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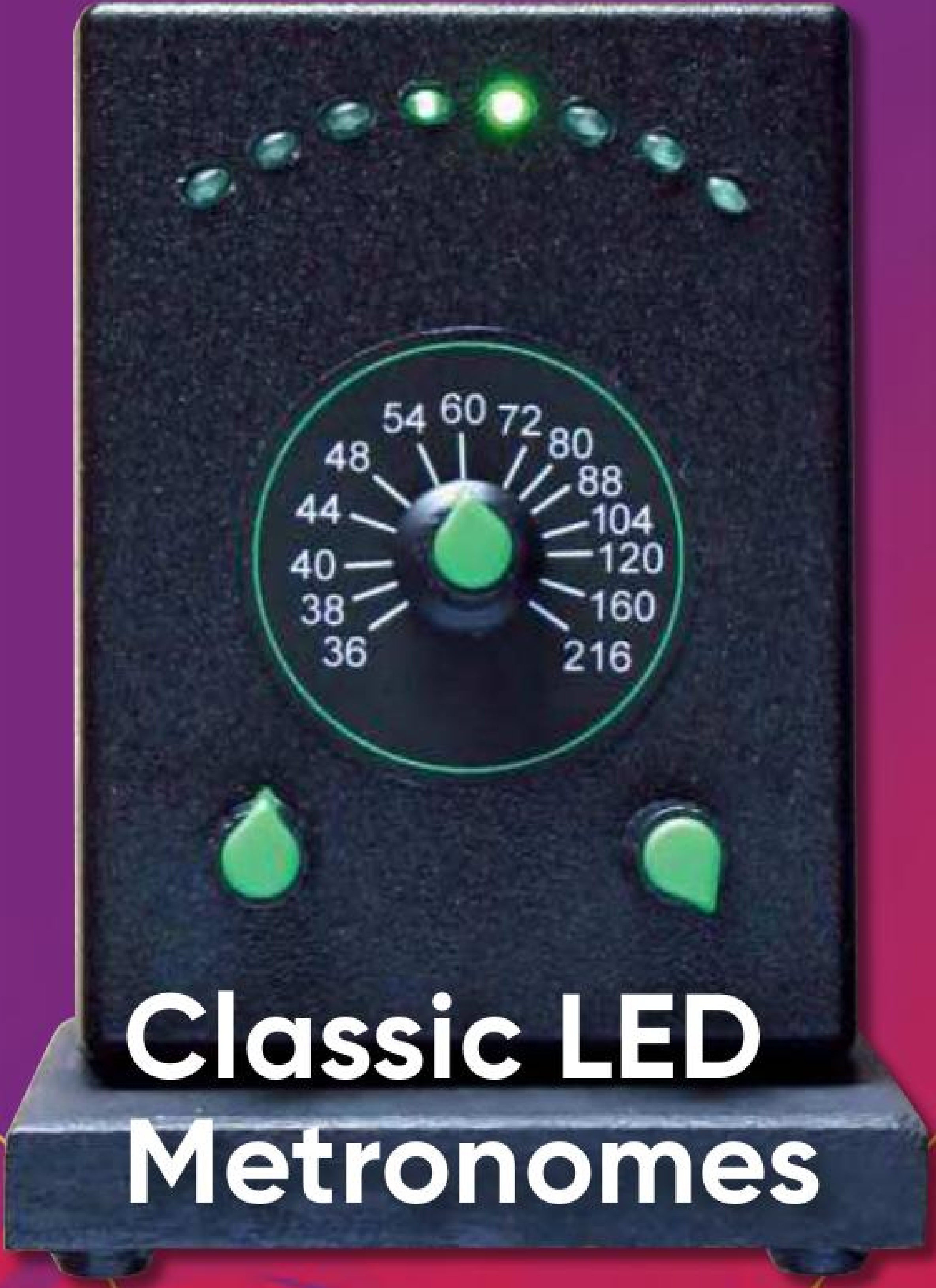

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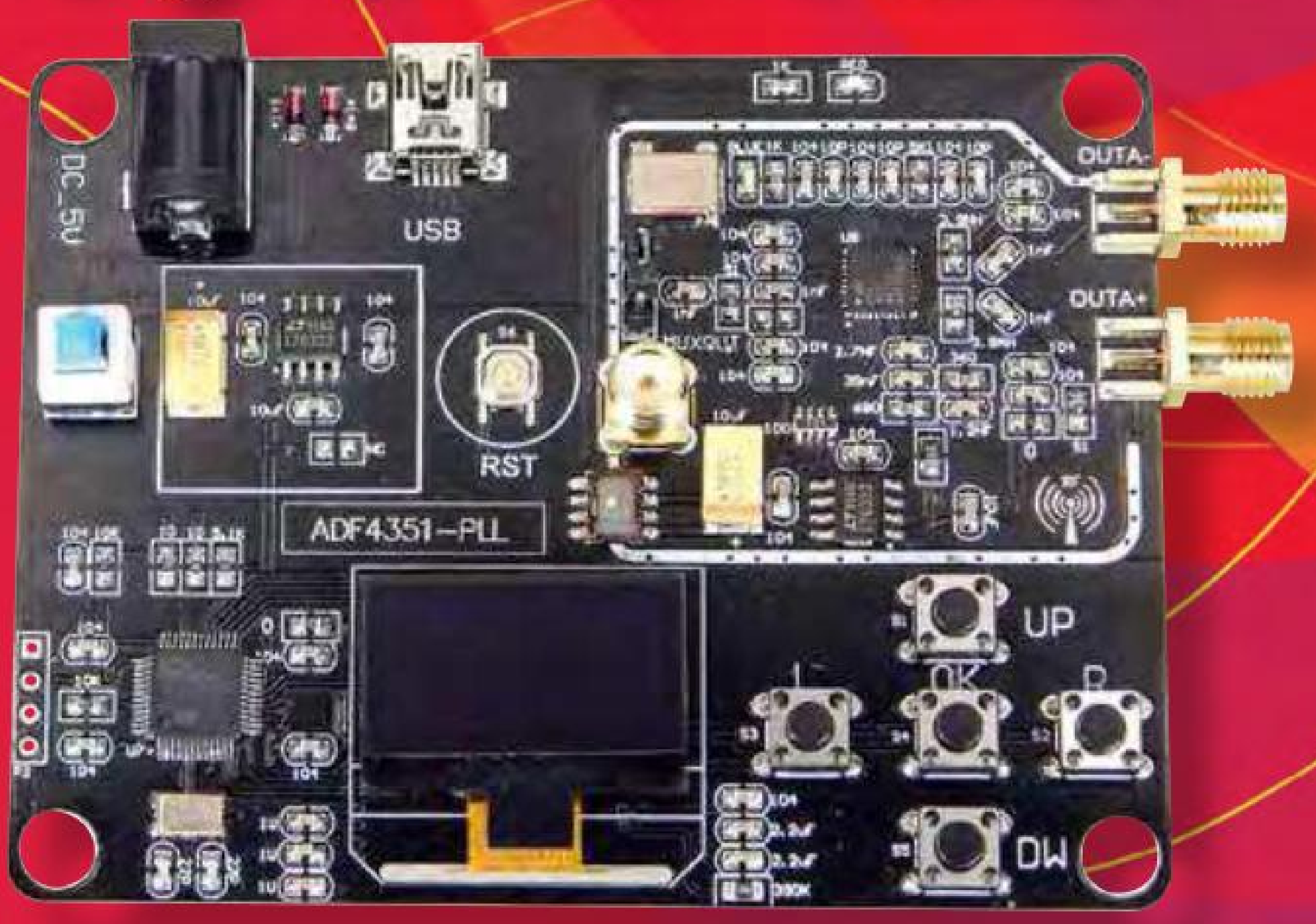

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Practical Electronics

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ISSN 2632 573X

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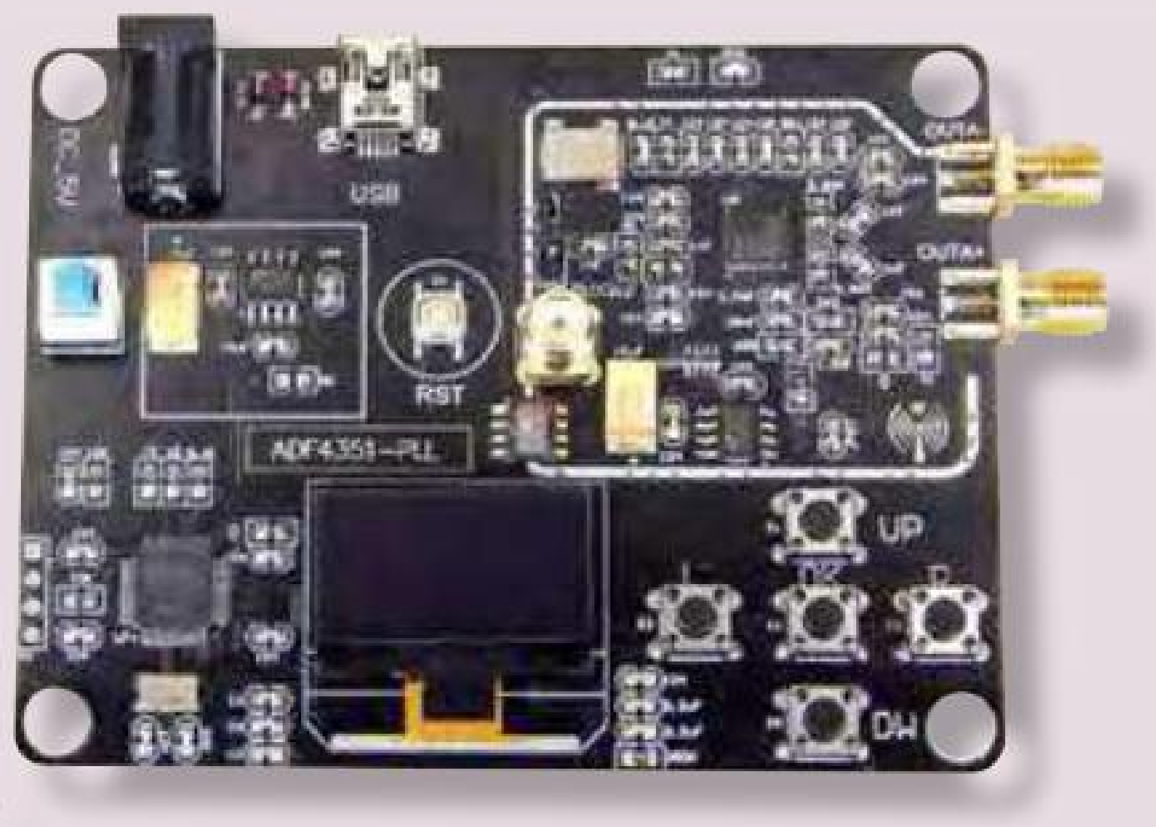

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The February 2023 issue of *Practical Electronics* will be published on Thursday, 5 January 2023 – see page 72.

WIRELESS FOR THE WARRIOR

by LOUIS MEULSTEE

THE DEFINITIVE TECHNICAL HISTORY OF RADIO COMMUNICATION EQUIPMENT IN THE BRITISH ARMY

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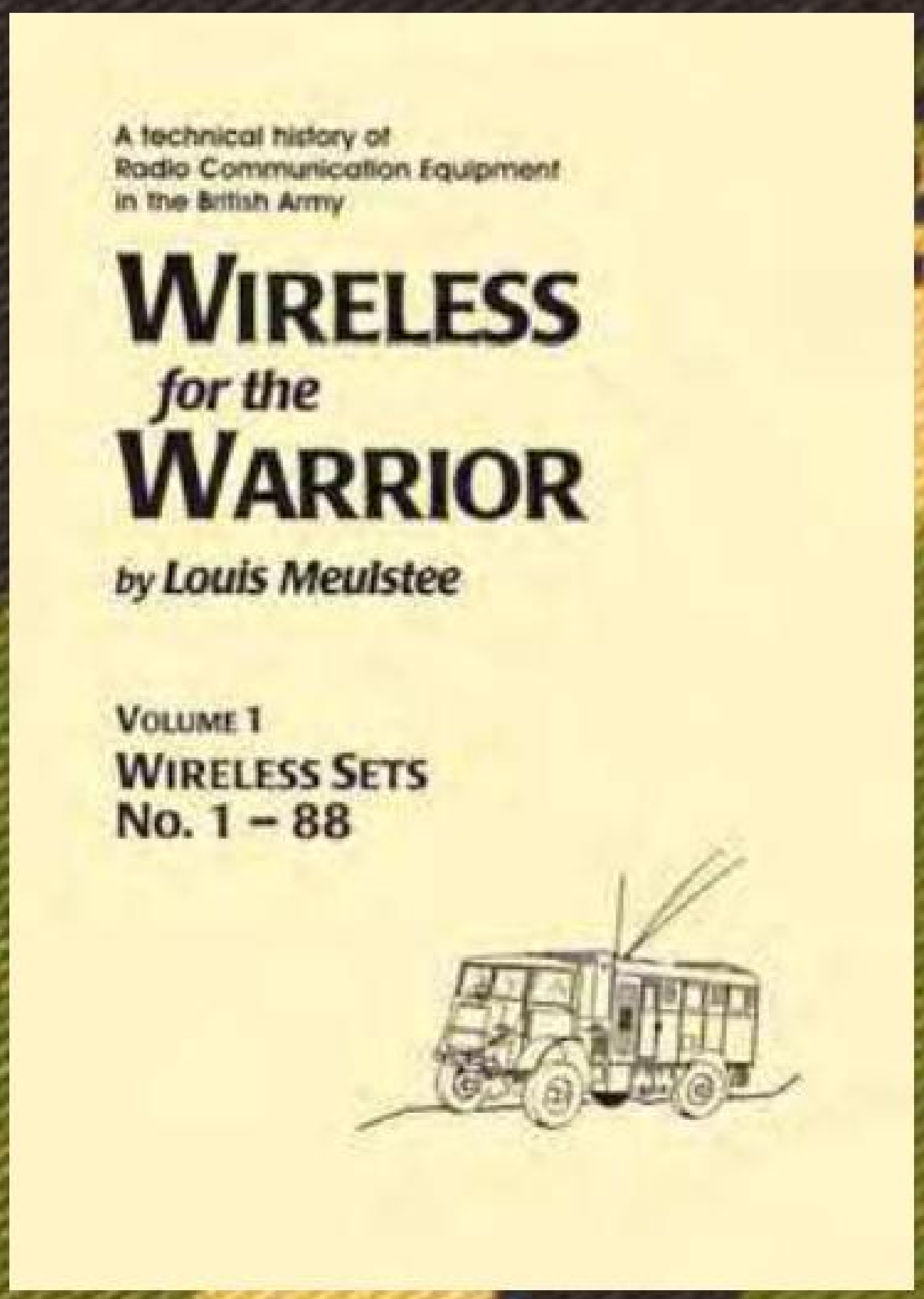
Volume 1 and *Volume 2* cover transmitters and transceivers used between 1932-1948. An era that starts with positive steps taken to formulate and develop a new series of wireless sets that offered great improvements over obsolete World War I pattern equipment. The other end of this timeframe saw the introduction of VHF FM and hermetically sealed equipment.

Volume 3 covers army receivers from 1932 to the late 1960s. The book not only describes receivers specifically designed for the British Army, but also the Royal Navy and RAF. Also covered: special receivers, direction finding receivers, Canadian and Australian Army receivers, commercial receivers adopted by the Army, and Army Welfare broadcast receivers.

Volume 4 covers clandestine, agent or 'spy' radio equipment, sets which were used by special forces, partisans, resistance, 'stay behind' organisations, Australian Coast Watchers and the diplomatic service. Plus, selected associated power sources, RDF and intercept receivers, bugs and radar beacons.



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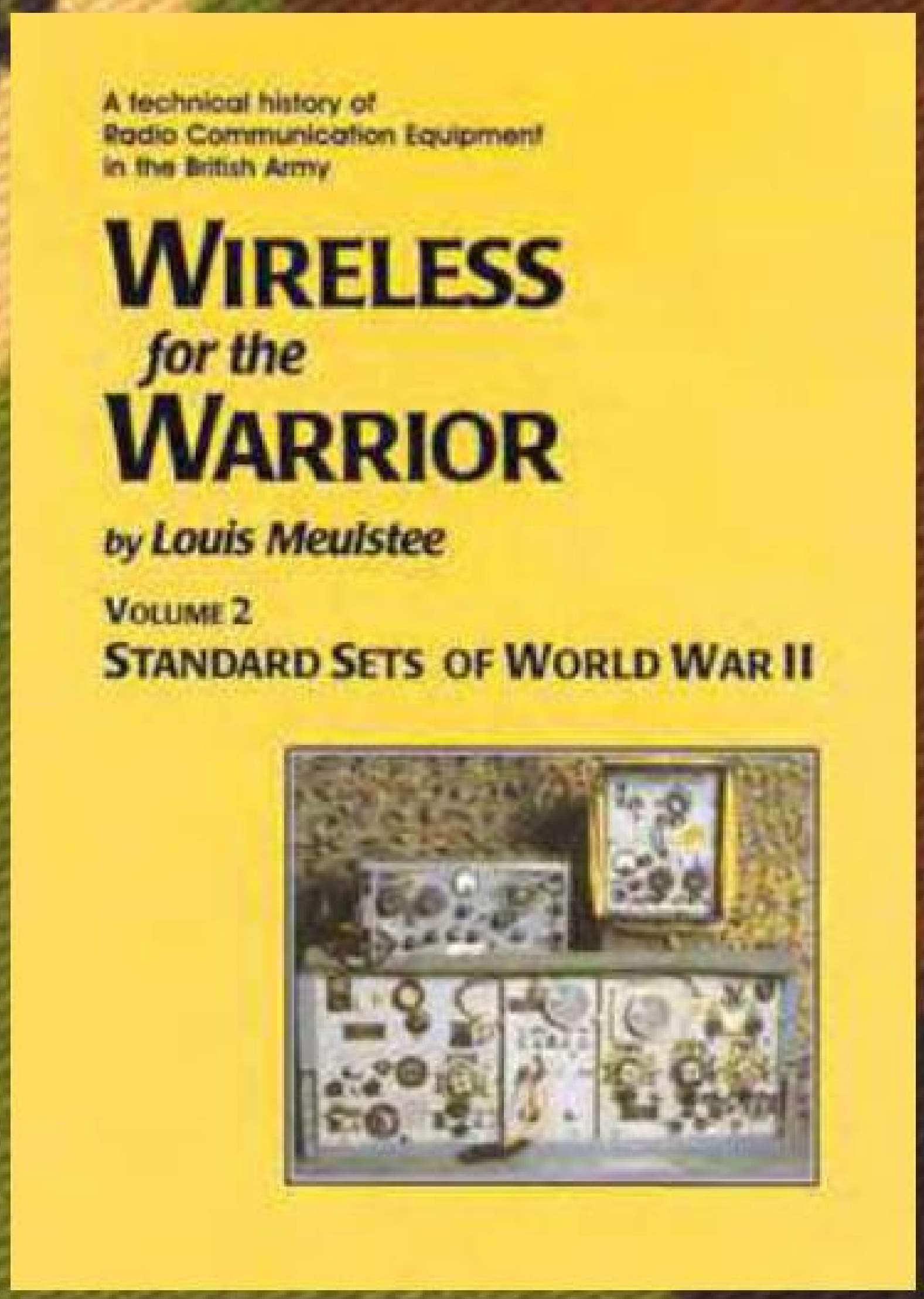

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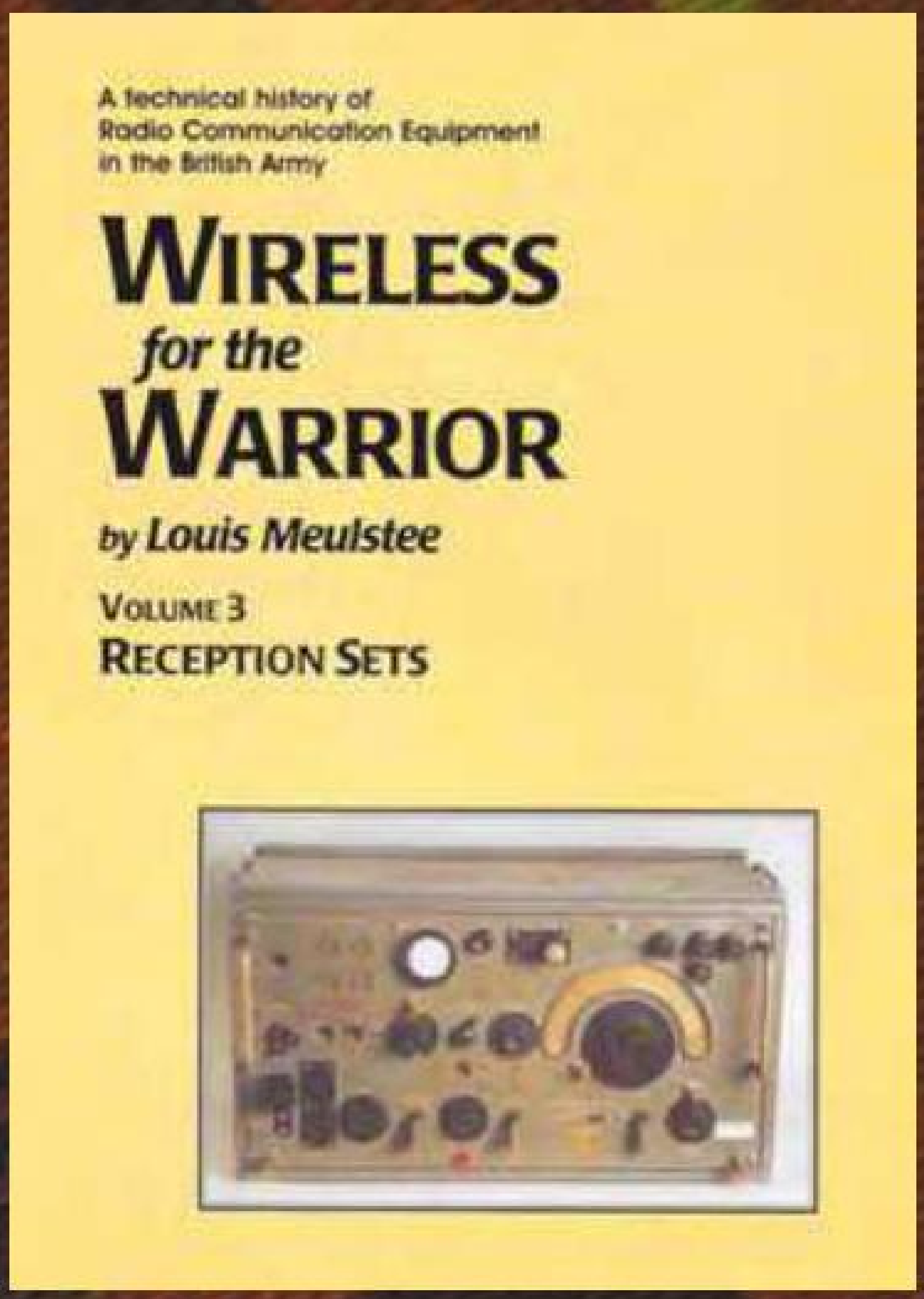

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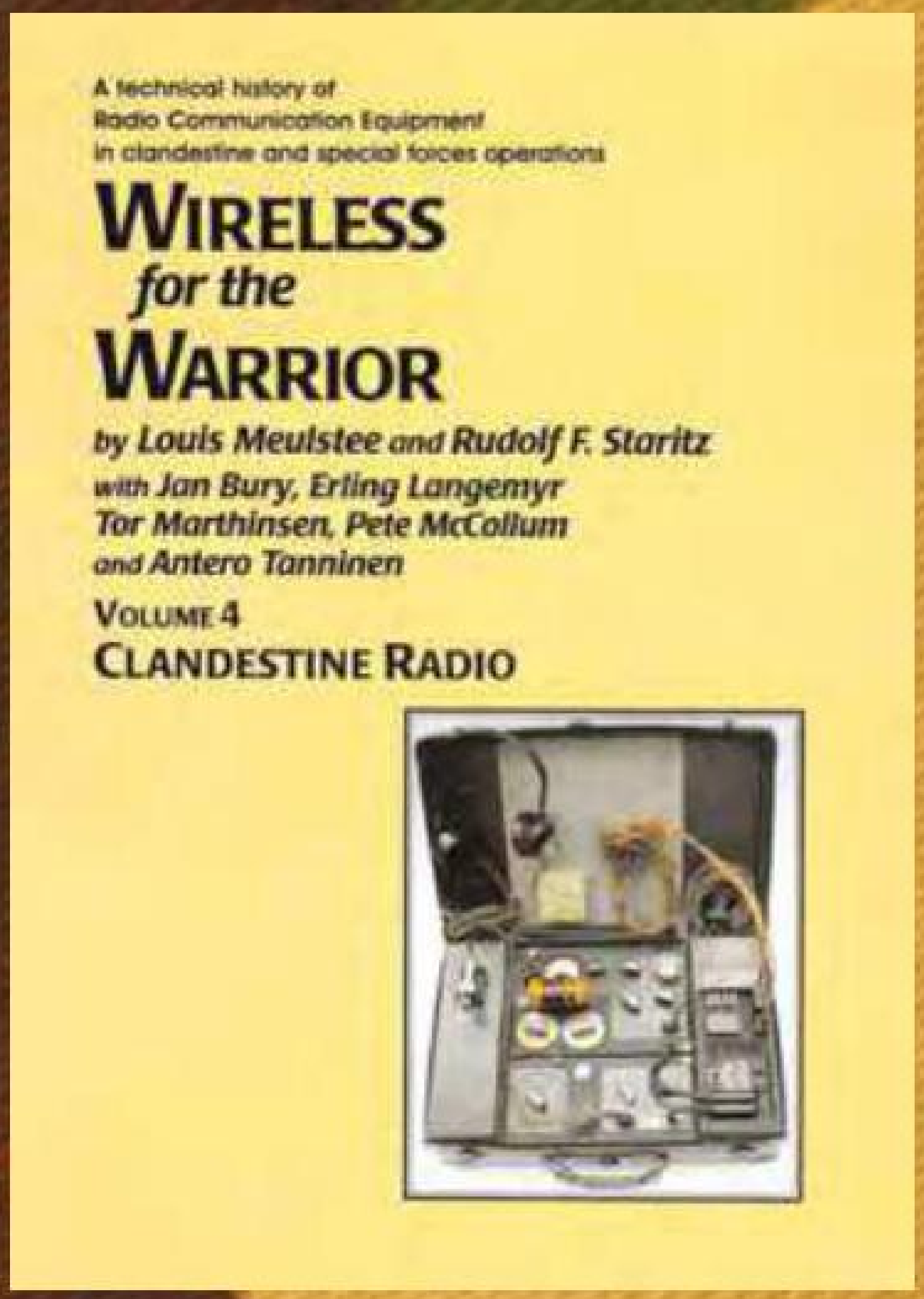

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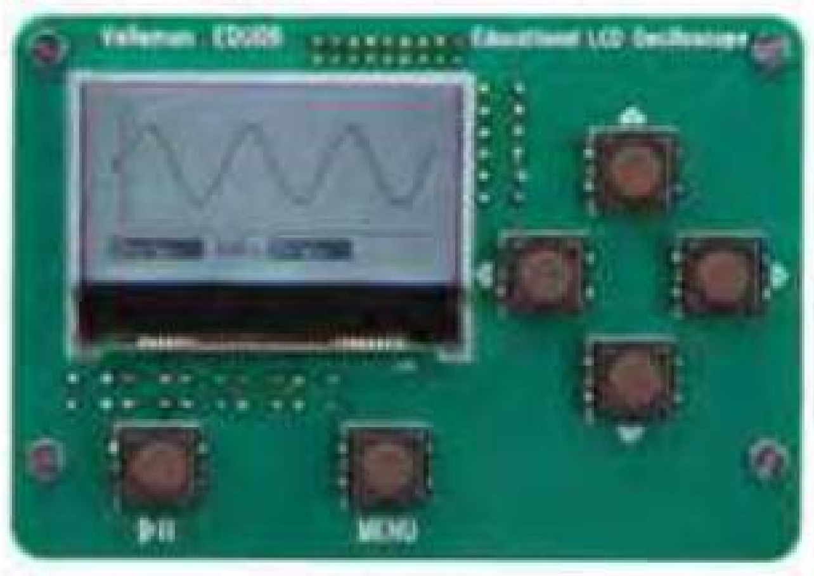

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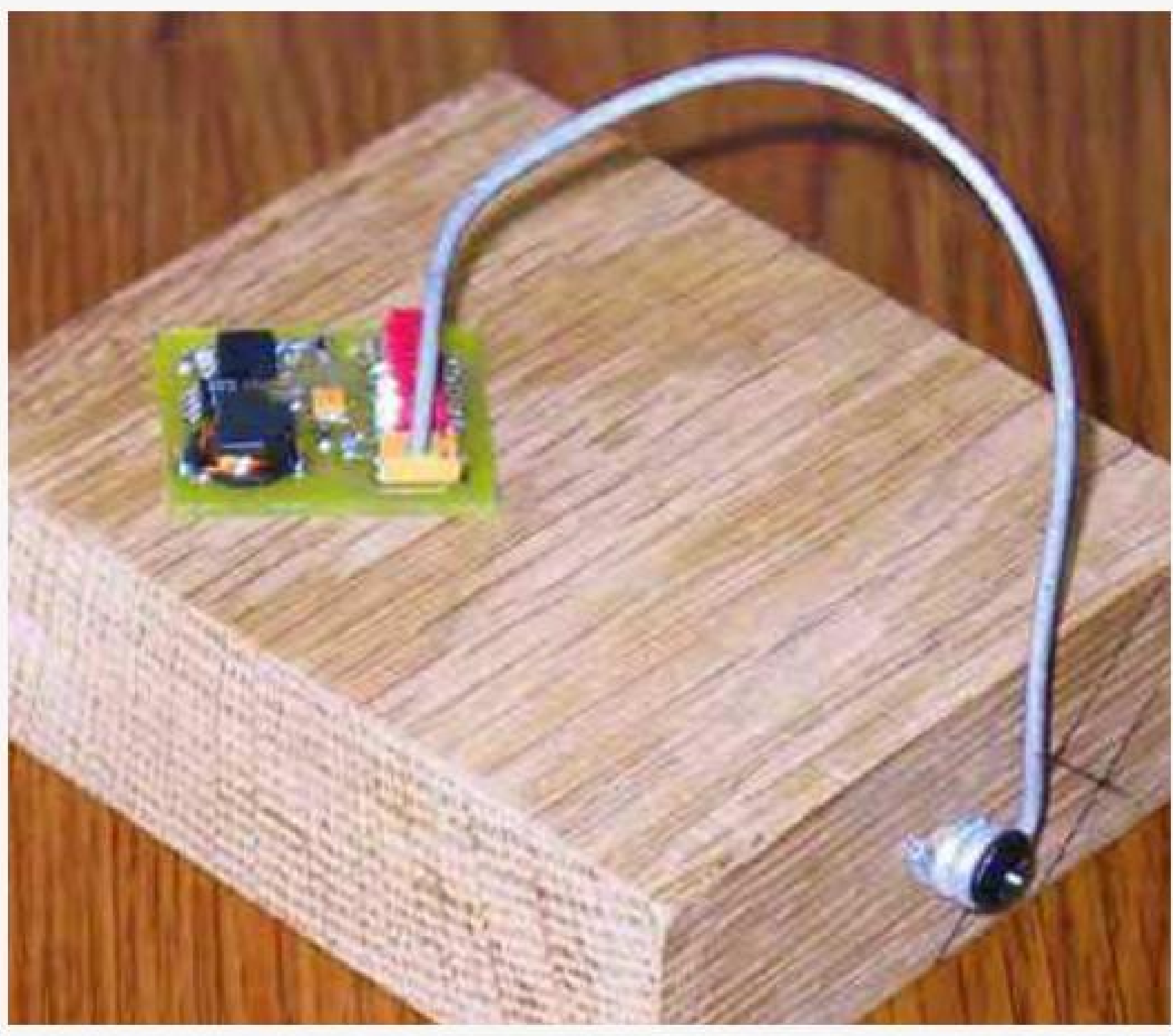
Editorial

SMD tips and tricks

I hope you enjoyed last month's article and project on soldering SMDs. As a follow up, I was pleased to hear from reader Mike Cowlishaw, who emailed me with a very neat SMD soldering tip. Like all great ideas it's completely obvious – but only *after* you've seen it! Mike wrote:

'I have been using SMD devices since the 1980s. I often made my own SMDs from through-hole devices by bending the leads 90° and snipping them off at surface level; this saved much hole-drilling! I was surprised, however, to read (on p.43) that "Fine-tipped tweezers are ideal" for holding SMD parts in place while soldering. I have the regulation two hands, but two hands are not enough to hold the device, the solder, and the iron in the right places at the same time.



'Accordingly (mid-1980s, I think) I came up with the simple device shown. The spring arm (a piece of wire from a coat hanger, or similar) holds the device to the circuit board and the board to the wooden base while you tweak the device's position, and it then holds it there while soldering (and helps ensure the device doesn't get too hot). This leaves both hands free for soldering, cleanup and inspection. I've used one of these for well over 30 years and found it makes the process easier, faster and more precise.'

Thank you, PE writers!

Another year, another 12 issues – I've said it before, and I'll say it again, *Practical Electronics* is nothing without its loyal band of fantastic writers. They work very hard every month to bring you original content that makes electronics accessible and inspiring. So, in no particular order – a huge 2022 'thank you' to Alan Winstanley, Mike Tooley, Ian Bell, Mark Nelson, Mike Hibbett, Clive 'Max' Maxfield, Phil Boyce, Julian Edgar, Barry Fox and Jake Rothman. Also, many thanks go to the hard-working 'back-office boys', Stewart Kearn, Alan Winstanley and Kris Thain, who keep the shop and website running smoothly... most of the time!

Just what I wanted!

'What can I get you for Christmas?' It's no one's favourite question, but for *PE* readers the answer is easy – 'I just want a subscription to my favourite magazine.' You can choose paper or online, and as a subscriber you can be sure that you will never miss a copy (or endure any price rises over the year). If you are already subscribed then we have a huge stock of PCBs for projects suitable for all levels of skill, ability and experience.

From all of us at *PE*, thank you for your support over 2022, have a very happy Christmas, and a healthy and peaceful 2023.

Matt Pulzer
Publisher

Raudive Voices Revisited

Techno Talk

Mark Nelson

It's 13 years since we discussed electronic communication with folk who have departed this life. The emergence of a new hobby product for conducting your own experiments offers a great excuse for examining this 'weird wireless' topic afresh.

The topic of 'Raudive Voices' (or Electronic Voice Phenomena – EVP) is somewhat ethereal and controversial, often (strongly) associated with the words 'debatable' and 'allegedly'. Some folk are firm believers, and in a research project conducted under laboratory conditions and involving more than 400 people, each of the participants claimed to hear mysterious voices. The sincerity of experimenters in this field is probably not in doubt. On the other hand, some commentators classify EVP with the paranormal, life after death and assorted other-worldly dimensions.

If, like me, you enjoy having your intelligence insulted now and again, and are willing to waste half an hour listening to total weirdness, then why not give this mind-bending 'science' a hearing?

What's it all about?

Michael Daniels, whose **PsychicScience.org** website is possibly the most accessible introduction to the subject, explains that EVP effects are now considered by researchers as one of a broader range of phenomena known as 'Instrumental Transcommunication' (ITC). Inconsequential experiments to capture spiritual voices by electronic means began in 1941, with the first academic discussion being published by the *Journal of the American Society for Psychical Research* in 1959.

The real 'breakthrough' came in the same year when the Swedish painter and film producer Friedrich Jürgenson was recording birdsong. When he replayed the tapes, he heard faint but intelligible voices in the background, even though there was no-one else in the vicinity when the recordings were made. He interpreted what he heard to be his dead father's voice, and after making more recordings, he subsequently claimed he'd heard a message from his late mother.

Following this, Konstantin Raudive, a Latvian psychologist who had taught at Uppsala University in Sweden, and who had worked in conjunction with Jürgenson, went on to make more than 100,000 recordings which he described as being communications with deceased people. Some of these recordings were conducted in a laboratory screened against electromagnetic signals. They contained words that Raudive said were identifiable and the clarity of the voices heard in his recordings was such that they could not be readily explained by normal means. It is in recognition of his efforts that the name 'Raudive Voices' is now given to this phenomenon.

The Ghost of 29 Megacycles

EVP was discussed in 1970 in the encyclopaedia *Man, Myth and Magic*, and during the early-1980s a new British magazine on the paranormal was issued with a cover-mounted flexi-disc (remember them?) of EVP recordings. However, it was not until a few years later that the subject attracted truly significant attention when the American investigative writer and broadcaster John Fuller wrote a book called *The Ghost of 29 Megacycles*. This substantial and seemingly level-headed paperback introduced the subject of EVP to the public at large. American investigators were convinced the dead could communicate with us by radio, setting up a half-million-dollar project called Spiricom to establish the proof.

It was pretty obvious that they would never establish scientific proof, even if they believed their findings were real. They argued that if it had been legitimate for Marconi to investigate the subject in the 1930s, then why should they not do so now using more sophisticated equipment. Where credibility broke down was that for some reason the 'transmissions' from the dead were confined to the 29MHz band, used actively by radio amateurs in the UK and elsewhere.

Even the book's author was not entirely convinced, conceding on the first page, 'This is a strange story. It is either true or it is not.' The book is still available at affordable prices, and you can also read it online at: **https://bit.ly/pw-jan23-29**

Don't try this at home?

I must admit that I don't feel like disturbing the dead, but if you feel like having a go, please feel free to visit **https://psychicscience.org/evp**, where you will find chapter and verse on how these mysterious voices can be recorded and enhanced, as well as listen to sample recordings and read more on the subject. The page warns that intense concentration is required in order to hear the voices on the tape, which usually has to be replayed several times in order to decipher the speech. You are recommended to work in a quiet room, wear headphones and confine your recording to a few minutes.

If you are feeling flush, you can buy a ready-made 'Raudive Diode Receiver and Microphone for Paranormal Research Ghost Hunting'. Check out the specification at: **https://bit.ly/pe-jan23-ken**

This improved version connects to almost any type of digital voice recorder and now incorporates a switched microphone to allow you to record your voice, calling out to the spirits, along with the output from the diode receiver.

Is that all?

Seemingly not. Interest in the subject has not gone away and apparently many people around the world are members of electronic voice societies (see **https://bit.ly/pe-jan23-evp**). They remain convinced that they can record the voices of the dead, receiving messages from the other side. The growing new wave of such belief systems is 'a seemingly irrational response to an increasingly irrational world,' as one commentator puts it.

And finally

Earlier this year, I mentioned a recreation of Ceefax, the BBC's teletext service (**https://worldofpaul.com**). Now there is Telstar, an emulation of BT's erstwhile viewdata service, Prestel. Its creator John Newcombe says: 'The aim of the system is to provide a viewdata experience for anyone who is interested in how things 'used to be'. Services in the past typically provided access via the public switched telephone network (PSTN) connection, and this is indeed how Telstar works. However, Telstar also makes use of a simple internet connection for modern internet modems.' Take a visit to **https://glasstty.com/telstar/** and be impressed.

Win a Microchip PIC32CX-BZ2 and WBZ451 Curiosity Development Board

Practical Electronics is offering its readers the chance to win a Microchip PIC32CX-BZ2 and WBZ451 Curiosity Development Board (EV96B94A) – and even if you don't win, receive a 15%-off voucher, plus free shipping for one of these products.

The PIC32CX-BZ2 and WBZ451 Curiosity Development Board, based on the WBZ451PE module, is the best development platform for evaluating the PIC32CX-BZ2 family of MCUs. It comes preconfigured with an out-of-the-box multi-protocol demo application and features a temperature sensor, a current measurement header, an RGB LED and a MikroElectronika mikroBUS socket to attach a plethora of sensors and add-on boards.

Wireless connectivity has become a mandatory feature for many products but often increases the cost and complexity of system design since generally it must be added as part of the larger application. To solves this wireless-connectivity design challenge, Microchip introduced its first Arm Cortex-M4F-based PIC family by integrating Bluetooth Low Energy (BLE) functionality directly into one of the system's most basic components, supported by one of the industry's most comprehensive developer ecosystems.

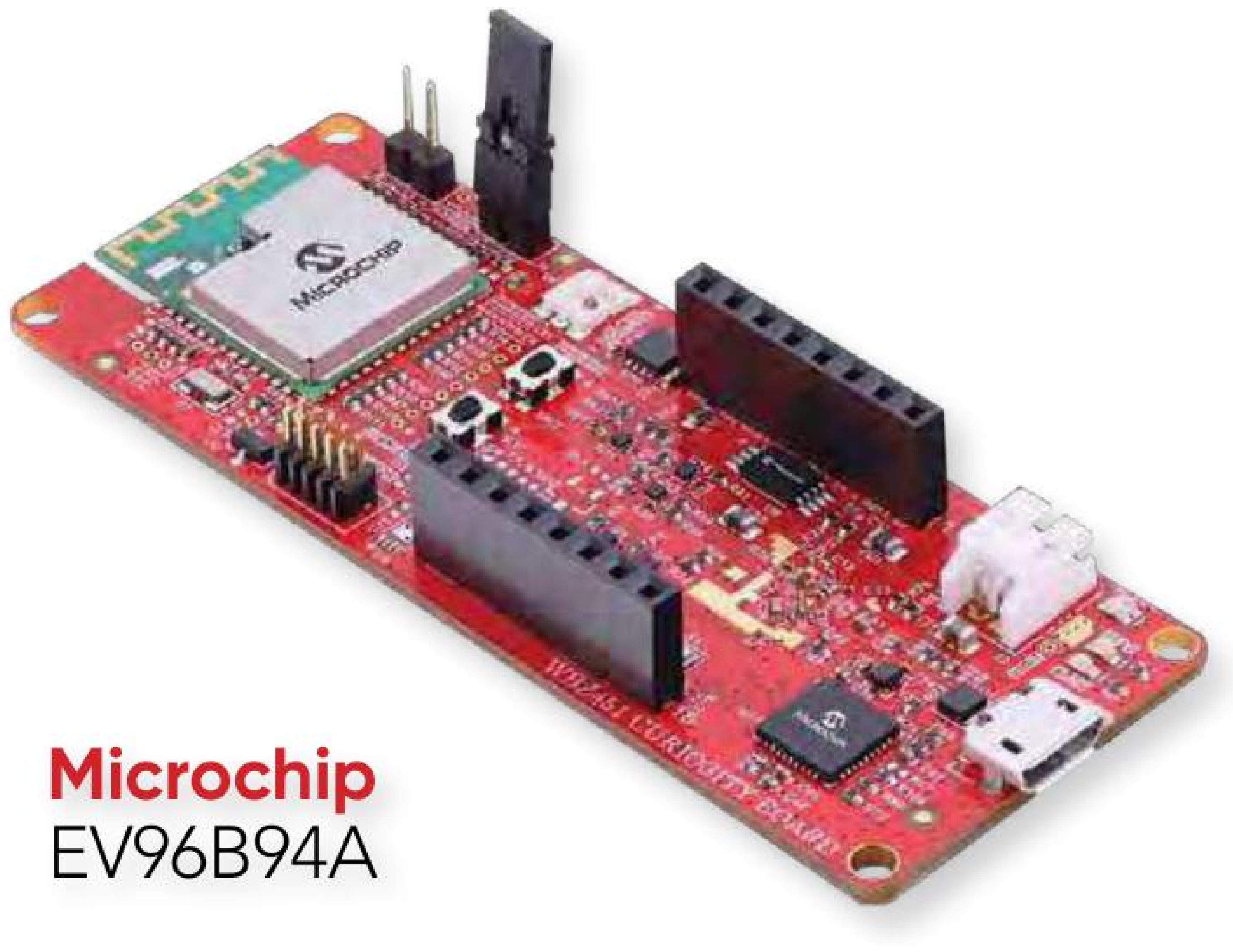
Microchip's PIC32CX-BZ2 family includes System-on-Chip (SoC) devices as well as global regulatory-certified, RF-ready modules. In addition to BLE functionality, the family includes Zigbee stacks and Over-the-Air (OTA) update capabilities. Hardware features include a 12-bit analogue-to-digital converter (ADC), multiple timer/counters for control (TCC) channels, an on-board encryption engine, and a broad set of interfaces to touch, CAN, sensor, display and other peripherals.

The family's 1MB of Flash memory supports large application codes, multiprotocol wireless stacks and OTA updates. AEC-Q100 Grade 1 (125°C) qualified packages further simplify wireless connectivity integration where highly robust solutions are required.

Worth $67.00 (approx £59.49) each

Free-to-enter competition

Microchip PIC32CX-BZ2 and WBZ451 Curiosity Development Board



Microchip
EV96B94A

How to enter

For your chance to win a Microchip PIC32CX-BZ2 and WBZ451 Curiosity Development Board or receive a 15%-off voucher, including free shipping, enter your details in the online entry form at:

https://page.microchip.com/PE-BZ2.html

Closing date

The closing date for this offer is 31 December 2022

September 2022 winner

Ed Rees

He won a
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Net Work

Alan Winstanley

This month, Google is ousted by Amazon (at home, anyway) and we try some typical smart light bulbs, testing out Alexa's 'skill' in controlling them. The latest energy labelling bands for LED bulbs are also explained.

The search engine giant Google has attracted its fair share of criticism and ire over the years, morphing from a search index with the motto 'Don't be evil' into an advertising broker that tries to monetise every corner of our online lives. Armed with your valuable profile data, advertisers can target web visitors with 'relevant' commercials. The Internet Advertising Bureau (IAB) pre-dates Google and is the self-help trade body that helps online media to comply with the EU's fearsome General Data Protection Regulations (GDPR). Many big brand names are IAB members, and Internet marketing is big business: in the early days of online advertising, UK commerce spent a mere £8m in the whole of 1997, compared with £12.5bn (yes, *billion*) in the first six months of 2022 alone, says the IAB.

Some very sophisticated techniques are used to profile a web user when they hop from one web page or social media post to another. Cookies are central to this, and some benign cookies are necessary anyway to enable a website or shopping cart to function properly. We tend to shrug off such creepy and silent monitoring when we visit, say, a furniture website, only to then see banner ads for the same furniture popping up after we jump to another website. Tellingly, Google's legacy 'Urchin Web Analytics Software support' page admitted that, 'In attempting to identify and track unique visitors and sessions [this way], we are basically going against the nature of the web, which is anonymous interaction.' (If ever you see '?UTM_blah=...' in a lengthy URL, it stands for 'Urchin Tracking Module' – it's Google's tracking system hard at work.)

Duck!

With online privacy concerns in mind, British TV viewers recently saw an ad campaign by DuckDuckGo (see: **https://youtu.be/QWpPyYlZXNI**), an alternative privacy app that claims to offer snoop-free web browsing and email protection. DuckDuckGo is at pains to remind web users how Google is 'watching them' and so their desktop browser extension uses a private search engine to eliminate a user's web surfing trails, or you can search the web directly at: **www.duckduckgo.com**

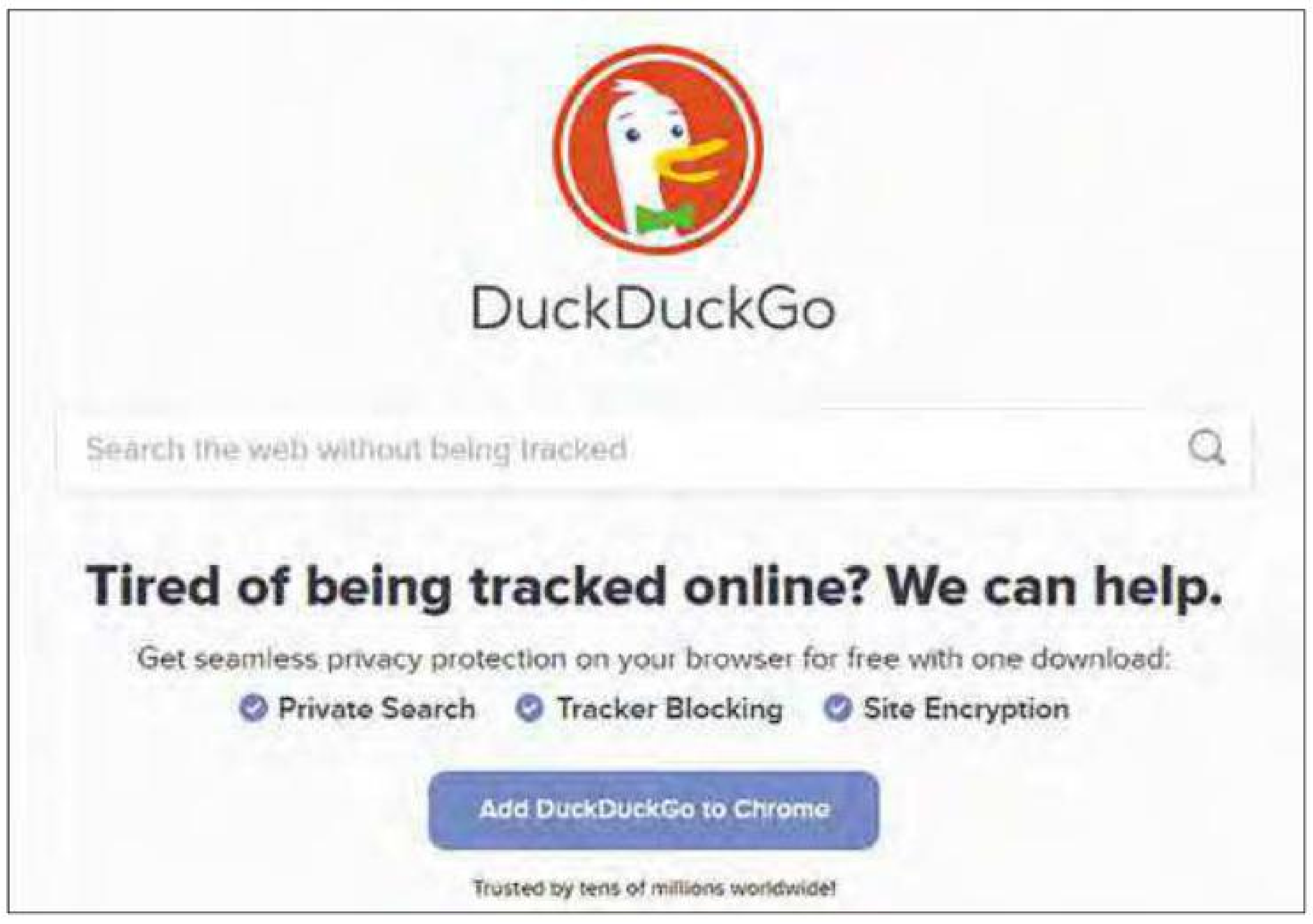
However, Google Search reigns supreme, with Microsoft's Bing still a distant runner up, at least as far as breadth and accuracy of search results are concerned. There are some Google functions that users would probably struggle to live without: Google Street View gives an insight into the contemporary street scene, and it can wind the clock back over a decade or more, so we can see our landscape changing over the years. Google Maps is the author's desktop go-to guide for finding addresses and planning journeys, and many use the free app for in-car navigation.

Looking at Planet Earth

More than 98% of the planet has now been mapped by Google, including (surprisingly) Russia though, (unsurprisingly), not China. Germany all but banned Street View outside Berlin and regional capitals on privacy grounds (see the blog at: **https://tinyurl.com/2j2275he**). Surfing around on Street View can be quite engrossing and it offers a taste of different worlds and cultures, whether in Britain or Bangkok. There is also no disputing the educational and informative value of Google Earth, which offers a 3D satellite-eye view of our place in the world: **https://earth.google.com**

Another handy app is Google Lens (see June 2022, *Net Work*), which will try to match images on a phone or tablet camera, or a photo gallery. Once the mobile app is installed, a Google Lens icon appears in the Google search bar for easy access, and it's great for identifying flowers, plants, bugs, artwork and more. It can also translate foreign text such as instruction manuals or packaging, or read text out loud. I can use the mobile app to translate foreign signs that appear onscreen, and desktop Google Chrome can search by image as well.

Despite bringing us these positive benefits, Google can be a source of irritation and it increasingly seems like it's grown too big to care. Google Maps, for example, does not recognise the common English habit of giving a house a name as well as a number, or sometimes just a name. There are countless British homes called *Dunroamin* or *Yew Tree Cottage* for example. In my case, one day a map pin suddenly appeared on Google Maps over someone else's location in town, wrongly labelled with *my* house name! It was nearly impossible to change Google Maps' error as their mindless 'Suggest an Edit' form did not accommodate English house names. Suspecting a case of identity theft, I seriously considered engaging a solicitor. After drawing a blank, eventually I logged into my Gmail account for a change, before going over to Google Maps and using the 'Suggest an Edit' link yet again. This time I got an automated email acknowledging receipt and promising a follow-up, but that never happened. However, the erroneous map pin silently disappeared a few days later, though an online login still shows my complaint as 'pending' – many months later.



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Service discontinued

Google's idea of handling complaints follows an established pattern. Regular readers might recall problems with my Google Home Hub (now, Nest Hub), an LCD smart speaker that for no reason suddenly stopped responding. Others blamed Google for a software or system update that had 'bricked' their Home Hub. It looks like Google forum staffers were feeding complaints through to the support team who raised a ticket number before going silent on the matter. I received several such support ticket IDs but never got an answer. My perfectly satisfactory 2–3-year-old LCD smart speaker was nearly worthless by then, and eventually I had no choice but to scrap the device. Google's press office failed to answer when I raised this with them, and more persistent tech writers than me also tried and failed.

Other Google services that are falling by the wayside include their Stadia cloud gaming platform, which never found traction and is closing in January 2023, with users receiving refunds. The 'Killed by Google' website (**https://killedbygoogle.com**) has 275 entries listing the history of every discontinued Google project. Some useful services such as Google Cloud Print, which was embedded into some Wi-Fi printers, are sorely missed, but others were clearly never going anywhere, including the instant messaging service Google Hangouts which is being dropped this month.

I then went further by dumping my Google smart speakers in favour of 5-inch and 8-inch Amazon LCD Echo Show displays that were being heavily discounted in price. These cheaper first-generation devices work perfectly well, and will prove ideal for many everyday users, especially if they are used by Amazon Prime subscribers. While Google states that Google Home services are 'subject to change without notice or obligation', Amazon promises to deliver updates for at least four years after the devices are removed from sale. I now enjoy seeing my gallery of thousands of Amazon Photos streaming to my Echo Show LCD screens: the 5-inch model is ideal for bedside or desktop use. Amazon Photo storage is unlimited for Prime users, but I bought extra storage at 100GB for $19.99 a year to carry more video files, making 105GB available in total.

10:10
14°
12 AM
3 PM
6 PM
9 PM
12 AM
15°
18°
17°
13°
12°
Bristol
"Today's forecast"

First-generation Amazon Echo Show smart displays have a lower-spec camera but will be perfectly fine for everyday users. Check Amazon for special offers.

It's not all good news for Amazon customers: Amazon Prime is now pushing Amazon Music subscriptions for an extra £8.99 a month after hobbling this enjoyable and rewarding streaming music service. Otherwise, song choices are now 'shuffled' with 'similar music' and you can only skip so many 'duff' songs per hour. Amazon's Alexa isn't entirely a match for Google Search either, but even though some users dislike the idea of smart speakers eavesdropping on us, I'm happy to try Amazon 'skills' to control some smart devices by voice, as I describe next.

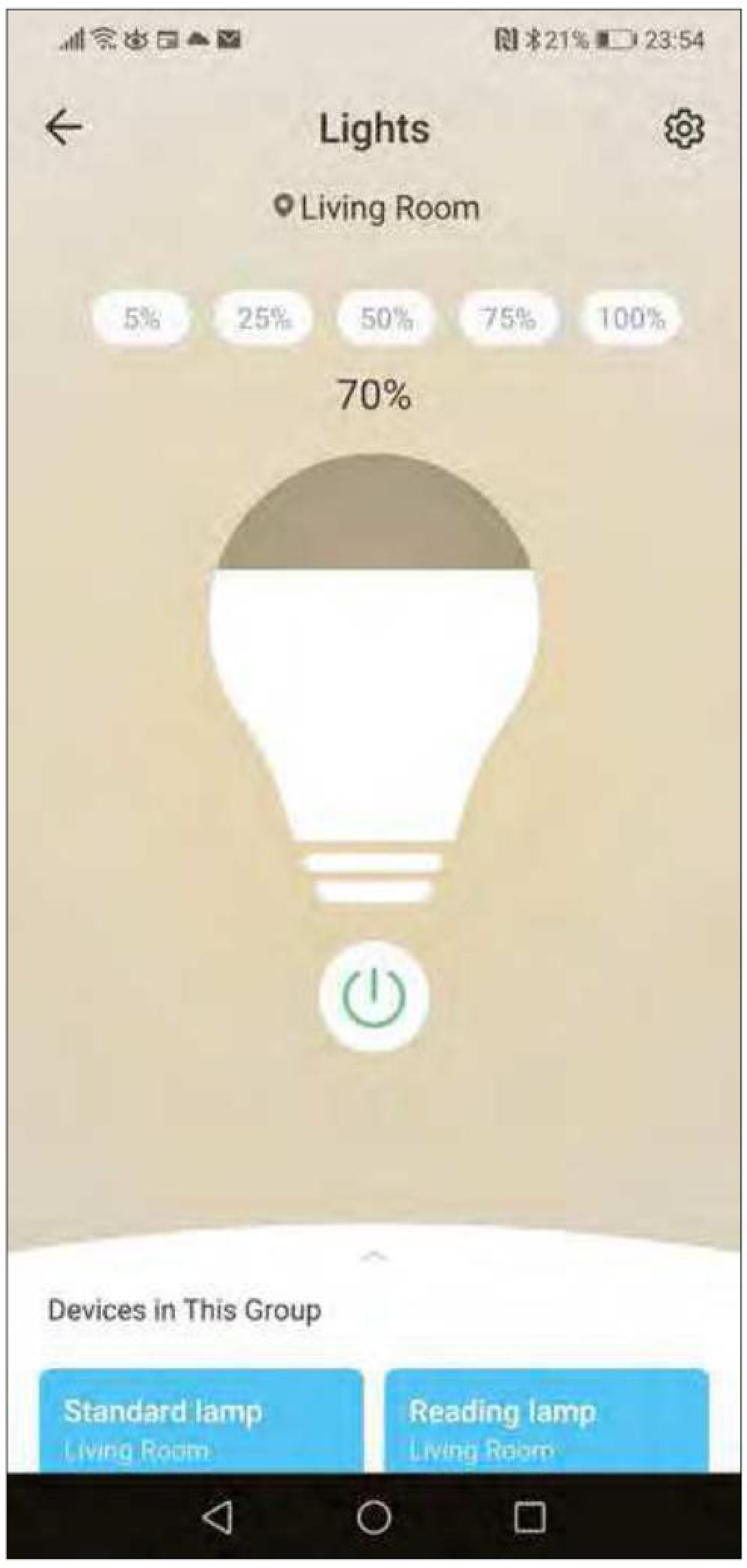
LED to believe

Last month, I introduced TP-Link's Tapo smart devices, which is an entry-level range of smart Wi-Fi sockets, bulbs and a few handy-looking peripherals. They are easy enough to configure using the Tapo app on a tablet or phone, and would be an ideal starting point for anyone wanting to harness smart devices without spending a fortune. Note that they are not interchangeable with TP-Link's Kasa smart device range, which needs the Kasa app instead.

As well as the Tapo P110 energy-saving smart socket featured last month, I've been trying out some Tapo smart LED bulbs. The Tapo L510B has a UK-style bayonet cap (B22) base and is

tapo
Smart Wi-Fi Light Bulb, Dimmable
2 PCS
tp-link
Tapo L510B
tapo
tapo

The Tapo L510B smart light bulb is dimmable and equivalent to a 60W light bulb.



The Tapo smart bulb can be controlled via the Tapo app or by using Alexa or Google Assistant.

dimmable, with a rating of 9W. The smart bulb is self-contained so, unlike some systems, it does not need a separate hub. A colour-changing LED bulb is also available (Tapo L530B). In my test set-up, several Tapo smart bulbs are used in light fittings between a duo of whole-home mesh hubs, so Wi-Fi coverage should not be a problem.

After a short delay the Tapo app found the new bulbs without too much fuss. The app allows these bulbs to be dimmed on demand, and there is a useful 7-day time switch and 'Away' mode, to give a burglar-deterrent effect during allotted hours. A timer switches the bulb on or off after a delay of up to 24 hours. I named each bulb – eg, 'standard lamp' and 'reading lamp' – in the app and they were then grouped together to unify their control. It all looked promising – on paper anyway.

Early on, I hit one or two frustrating setbacks, with either or both bulbs sometimes becoming 'unreachable' and not responding. Occasionally, they fell off the network and rebooting them didn't always work either, so once or twice they were re-installed or factory-reset (a process of turning them on and off repeatedly). This is nothing like as bad as the totally crazy factory-reset routines for 'C by GE Bulbs' shown in a YouTube video at: **https://youtu.be/DgIsn0Zac3o** – try not to laugh, or cry!

Additionally, the Tapo smart socket (see last month) is working well, powering up a smart TV, but I wouldn't use it to switch a heavy mains load like an electric heater or any current-hungry white goods.

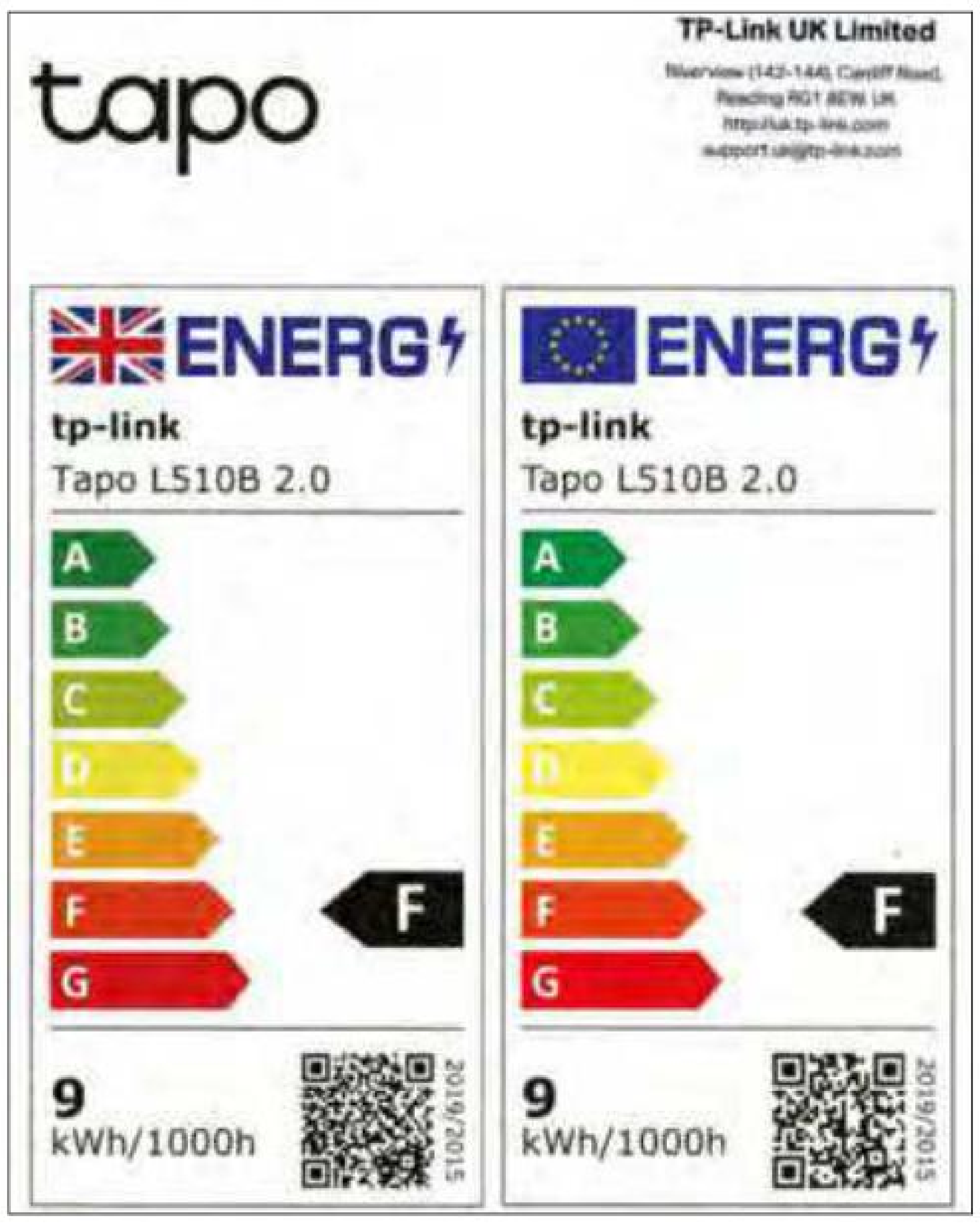
Alexa, good night

Then it occurred to me that the Amazon Echo Show devices could also voice-control the Tapo devices by installing the Tapo 'skill'. This is easily achieved by telling Alexa to install it, or I could set it up via the Alexa app instead. In theory, automated routines (so far untested by me) can be set up such as 'Good night,' which could turn everything off, and the Tapo app offers 'Sunrise' routines that use a smart bulb to simulate sunrise.

Testing this new regime over the last few weeks revealed some practical limitations though, highlighting that all is not ideal in the smart-device world. Sometimes a Tapo bulb responds immediately, but occasionally there's a disconcerting delay before a lamp finally switches on a few tens of seconds later, if at all. The Tapo app may also flag up an 'Unreachable' warning symbol on either one of the bulbs. The app and the smart bulbs seem to get out of sync, at least for a short time, leaving me with no idea whether the smart device is actually on or off until the system catches up with itself again. There are so many variables at play that it's been impossible to fine-tune the system to improve reliability any further.

The Tapo range has some handy smart devices, including 1-gang and 2-gang light switches (S210/ S220) to control room lighting, but only a practical test at home would prove how well they worked for you. A stick-on smart contact sensor (T110, £15) monitors doors, windows, fridge doors, filing or medicine cabinets or even the mailbox. It can push messages or activate a smart bulb (see: **https://bit.ly/pe-jan23-tapo**). It also requires the separate Tapo Hub H100 (approx £30), a small plug-in chime unit with the form factor of a wireless doorbell. Their smart PIR sensor (T100, £28) detects movement, and a handy, multipurpose stick-on smart button (S200B, £15) might make a doorbell, lighting controller or an alarm-call for the elderly, for example. These peripherals also need the Tapo Hub H100. Tapo Wi-Fi cameras and LED lighting strips are also sold.

In summary, I guess budget-price systems like these are alright as far as they go. My own domestic set-up works well enough most of the time, and the benefits largely outweigh any drawbacks. Hopefully it will settle down in due course, but I sometimes find Alexa stubbornly disobedient when the system isn't responding as expected. Before taking the plunge, the best port of call is the Tapo website which details all these devices and how they work together. So to learn more, visit: **www.tapo.com**



An 'F' rating for a 9W LED lamp isn't as bad as it looks. Higher-efficiency light sources are under development. Users scan the QR codes for more data.

EPREL Showers

As every European consumer knows, many electrical products carry an EU energy label indicating its energy efficiency, based on a 25-year-old system that was intended to inform/influence our buying habits. Appliances were originally rated A to G, then A+++ to G to accommodate more energy-efficient units, but so many products ended up jostling in those top 'A' tiers that makers had no incentive to evolve any further: they couldn't improve on A+++. The system therefore reverted in 2021 to show ratings of A-G again, with energy bands 'telescoped out' to allow consumers to distinguish between different models more easily.

The European Commission explains that the new scale has been designed so that very few products will initially be able to achieve the top 'A' and 'B' ratings at all. This will allow room for waves of more efficient products to arrive and work their way up the scale. Currently, the most energy efficient products will typically be labelled as 'C' or 'D', but simple market forces should encourage progressive makers to reach 'A' and 'B' in due course.

Some new elements have also appeared on the revised energy labels, including a QR code that links to an EU product database called EPREL

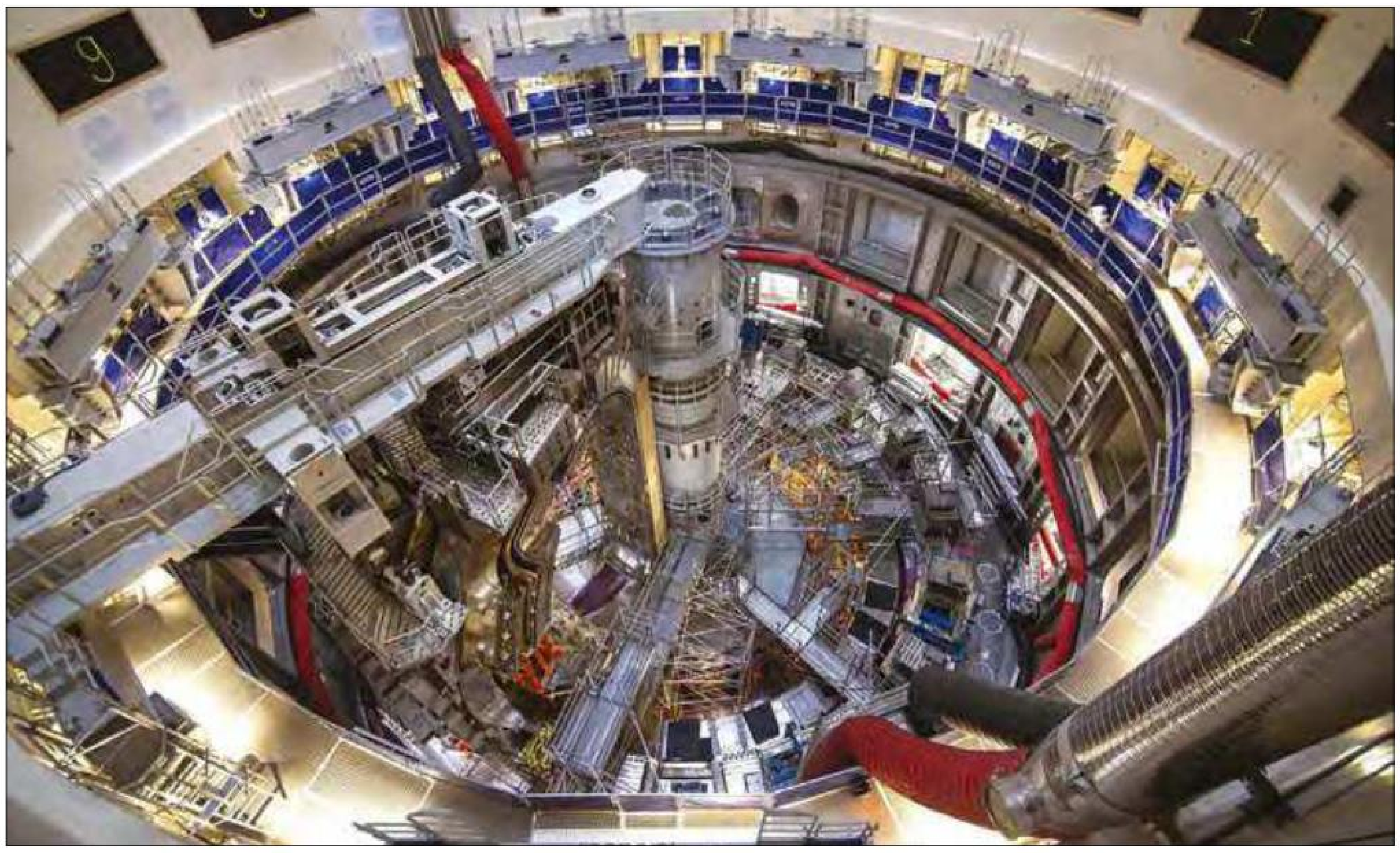
(European Product Registry for Energy Labelling) where consumers can find out more details. Many more products, including car tyres, water heaters and solid fuel boilers are indexed there too. The public face of the database is still in Beta, but the go-to address for future reference is: **https://eprel.ec.europa.eu**

Of the two QR codes printed on my Tapo smart bulb energy label, one clicks through to TP-Link's website while the EU label jumps to the EPREL database showing full technical data (and you'll feel sorry you asked).

I noticed how a stock 42W halogen bulb was rated 'D' on the old scale, yet my Tapo LED bulbs were rated 'F'. The market for what the EU now calls 'light sources' (bulbs, LEDs, modules and so on) has changed due to the urgent need to raise efficiency and conserve energy. Since the A-G thresholds were revised, the current generation of LED bulbs have been demoted down the scale. The Tapo consumes 9kWh/1000 hours (9W in old money) and, as LED bulb energy ratings are based on lumens/watt (lm/W), it outputs 806lm at 9W (ie, 90lm/W): hence its paltry 'F' energy rating which sounds a lot worse than it actually is. For interest, a tungsten filament bulb emits about 12-14 lm/W and wastes over 95% of energy consumed as heat, so my halogen bulb would now be 'G' rated. Future LED bulbs will need to be two or three-times more efficient than today's models if they to reach the new 'A' rating (210 lm/W) – Philips has already nearly achieved this with prototype 'TLED' light tubes. Readers can expect the energy efficiency of LED bulbs to climb steadily in coming years as they aim for that 'A' rating.

And finally

The ITER nuclear fusion plant under construction in France (see last month) has received the first of six 'poloidal field coils' destined for the *tokomak*. The 200-tonne 'pancakes' have taken ten years to develop and are manufactured in Russia. One of three magnetic systems, the coils will be positioned horizontally outside of the ITER vacuum vessel to shape the plasma and contribute to its stability by 'pinching' it away from the walls, says ITER. Many more components and coils made for ITER by international manufacturers have already been safely delivered to the massive site, which continues to come together ready for 'first plasma' in 2025. There's more at **www.ITER.org** and readers might enjoy ITER's new video at: **https://youtu.be/f9nW01PBOOQ**



The ITER nuclear fusion site in France continues to take shape. – this view looks inside the 30m-deep tokomak pit (Photo: © ITER Organization)

Recently, my Samsung Smart TV suddenly refused to connect to the Internet, citing 'No network connection'. I ripped everything apart, including changing Ethernet cables and swapping Ethernet ports on a nearby access point, but it made no difference and the stubborn problem dragged on for weeks. I feared that the Ethernet port on my TV must have failed, but the TV still connected to the network-attached storage on my LAN, so some parts of the network were working properly. It looked like a DNS look-up problem, perhaps with my ISP, so after much hair pulling, I eventually found a solution: I changed the DNS address nailed into the TV's network settings by choosing 'Manual' instead of 'Automatic' and entering 8.8.8.8 instead. The TV immediately sprang into life! This DNS IP is a Google public DNS address (see **https://bit.ly/pe-jan23-dns** for an explanation); others worth trying include 8.8.4.4. or Cloudflare's 1.1.1.1. The latter one is suggested by my own ISP, so I configured those in my router, and now all is well. If you suspect DNS problems, try those IP addresses instead.

That's all for this month – I'll sign off by wishing all readers a Happy Christmas and look forward to you joining me next month for more *Net Work*.

The author can be reached at:
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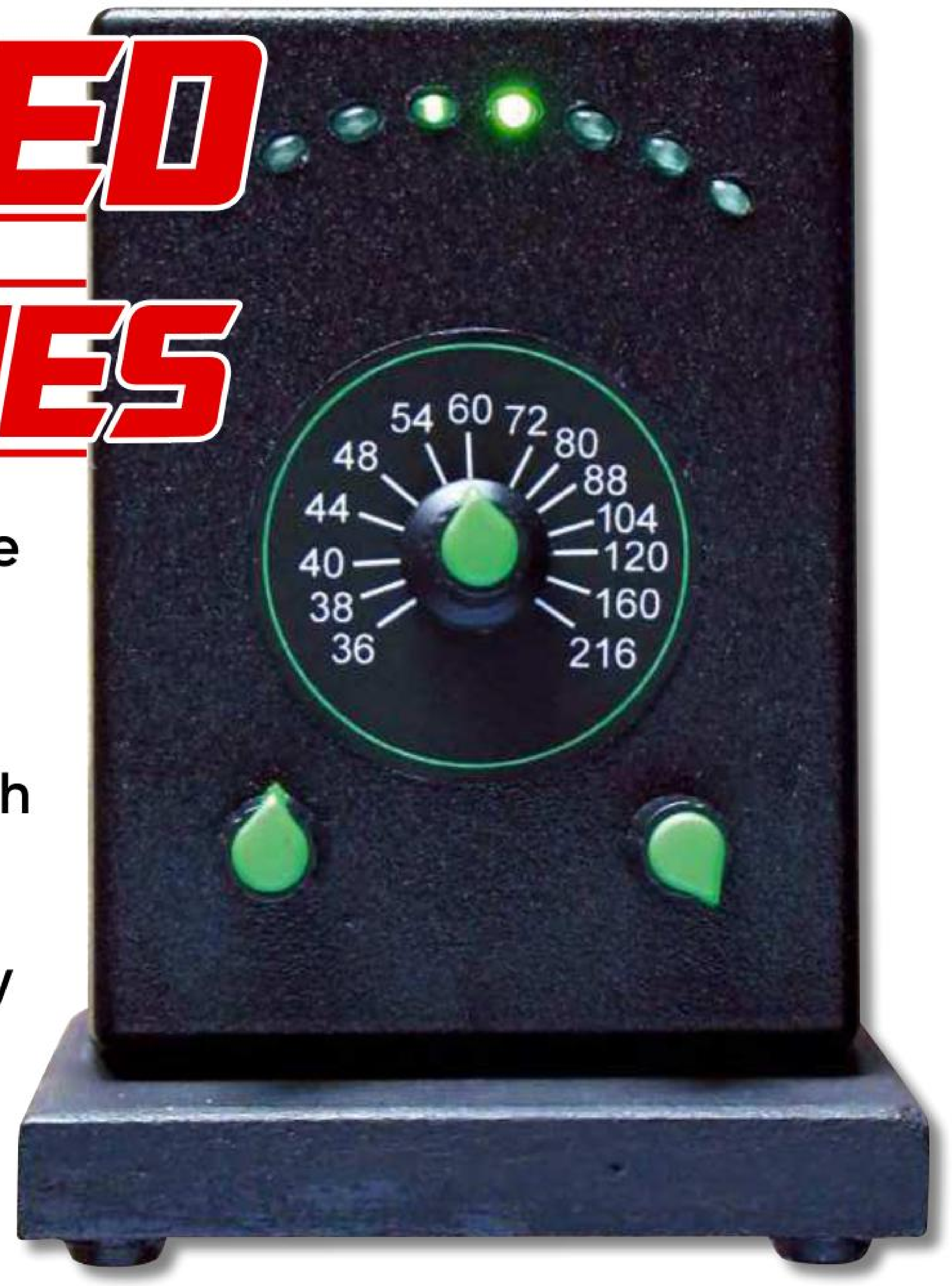
Classic LED Metronomes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These two Metronome designs simulate the classic mechanical, inverted-pendulum metronome with its baton-like pointer swinging left-and-right, producing a click at each extreme. Both designs use only discrete components and simple logic chips, making them easy to understand and build. Plus, they are both great projects for a beginner.

By Randy Keenan

I dislike typical 'modern' electronic metronomes that only click and/or blink once per beat. I came up with these designs to better simulate the mechanical metronomes that I know and like. Both designs light a series of LEDs, accompanied by a speaker that produces beat sounds.

The first design uses eight LEDs and fits in a standard plastic case, while the second, slightly more complicated design has 10 LEDs and is housed in an elegant custom-made timber case. So the latter is a good project for those readers who have some woodworking experience.

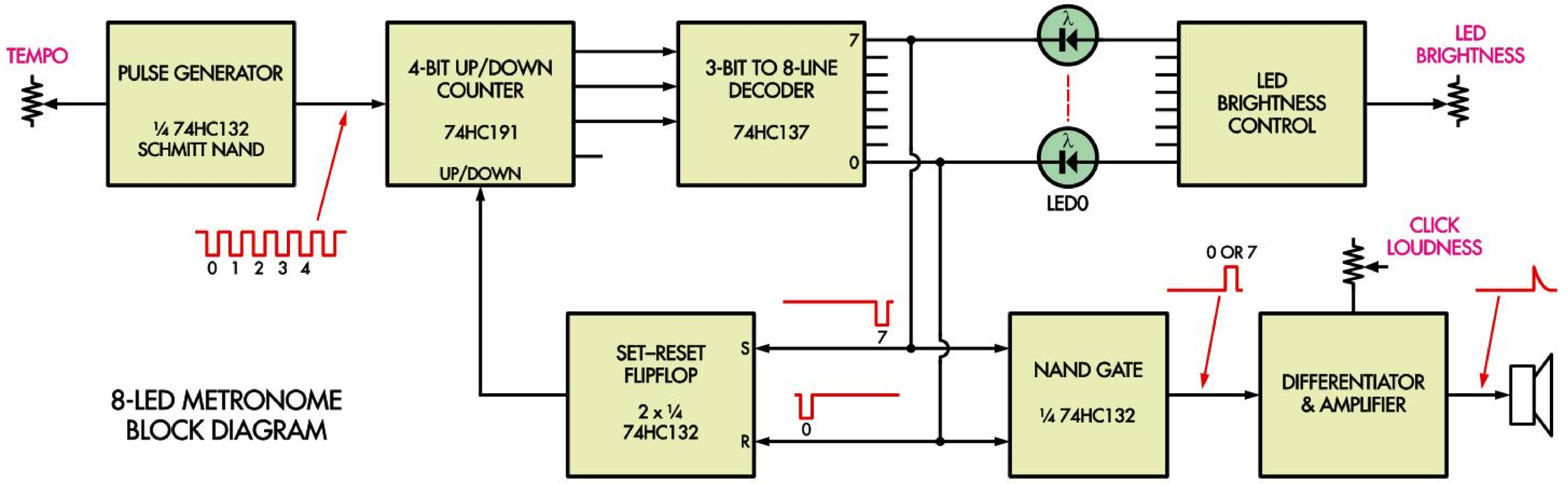
In both cases, the LEDs are arranged in an arc and light up in sequence, forward and reverse, to mimic the swing of an inverted pendulum. A click at each end of the LED arc further simulates a mechanical metronome. A typical metronome tempo range is 40-208 beats/minute, a ratio of 5.2 to one; in these Metronomes, the range is extended to 36-216 beats/minute, a ratio of six to one.

Either project is excellent for a beginner; there are no high-frequency signals, high voltages or tricky wiring involved. Nor is there any need to program a chip with software. However, some measurements and adjustments will be needed to calibrate the instruments after construction, given the expected component tolerances.

Two designs

The slightly simpler *8-LED Metronome* uses 74HC-series logic ICs and can be battery-powered, while the 10-LED Metronome uses CD4000-series logic ICs and is intended to be powered from a plugpack. The two circuits operate similarly: a pulse generator clocks an up/down counter IC at the rate required for the desired tempo. Another IC decodes the counter value to light the LEDs sequentially.

A set/reset flip-flop (SR-FF) switches the counter direction when either end LED is lit, giving forward and reverse LED sequences. The click is produced by ORing the signals to the end LEDs, followed by a differentiator to shorten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¼ 74HC132
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3-BIT TO 8-LINE DECODER
74HC137
7
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LED7
LED0
LED BRIGHTNESS CONTROL
LED BRIGHTNESS
0 OR 7
CLICK LOUDNESS
SET–RESET FLIPFLOP
2 x ¼
74HC132
S
R
7
0
NAND GATE
¼ 74HC132
DIFFERENTIATOR & AMPLIFIER
8-LED METRONOME
BLOCK DIAGRAM

Fig.1: the 8-LED Metronome is based around three 74HC-series digital logic ICs. The 74HC132 generates pulses at a selectable frequency. These clock the 74HC191 counter, and its three-bit output drives the eight LEDs via the 74HC137 decoder chip. The remaining three gates in the 74HC132 quad NAND package are used to form a set-reset flip-flop to reverse the LED chaser's direction each time it reaches one end, and to generate a pulse from the speaker.

The LED metronome comes in two versions; one with eight LEDs and another with 10 LEDs (shown in this photo). The case to house it can be as simple as a small timber frame with a clear plastic panel at the front.

the pulse and a one-transistor amplifier to drive a small loudspeaker.

The block diagrams of the two *Metronomes* are shown in Figs.1 and Fig.2. In the *8-LED Metronome*, the tempo pulse is generated by a Schmitt-trigger NAND gate (part of a 74HC132). This clocks four-bit up/down counter IC2 (7HC191). Only three of the four binary outputs are used to drive 3-to-8-line decoder IC3 (74HC137) that lights the LEDs in sequence (eight is the 137's limit). The SR-FF is made from two more NAND gates in the 74HC132.

In the *10-LED Metronome*, the pulse is generated by a CMOS version of the ubiquitous 555 timer. It clocks four-bit up/down counter IC3 (CD4029) which drives decoder IC4 (a CD4028) with 10 outputs. The SR-FF logic is again provided by two gates from IC1, although it is a different logic chip.

Both versions enable the LEDs at each end of the arc to flash brighter. You could also use either of these circuits anywhere an LED 'chaser' is needed.

LED options

There are many options for the LEDs in these *Metronomes*. The parts lists indicate the suggested LEDs, but other sizes, shapes and colours can be substituted. The two end LEDs could even be different from the middle LEDs.

However, all LEDs should have high luminous intensity, ideally at least 4000mCd (sometimes called 'super-bright'). This is to reduce power consumption. For the *8-LED Metronome*, that maximises battery life, while in the 10-LED design, it limits the load on the CD4028 driving IC to a safe level.

Both *Metronomes* were made using 5mm oval LEDs: green for the *8-LED* version, and red for the *10-LED* version. I used oval LEDs because they glow in a line rather than a dot, providing a more interesting display. 3mm and 5mm round LEDs are also suitable. Tinted and diffused lenses look best.

You can use different LEDs from those specified, but you might need to adjust some resistor values.

The 8-LED version

The LEDs should be of the same type and matched; but if using different LEDs at the ends, use matched LEDs for those two and separately matched LEDs for the rest. The minimalist circuit is shown in Fig.3 and works as follows.

Schmitt-trigger quad NAND gate IC1d is configured as a pulse generator. The pulse frequency, and thus the metronome tempo, is determined by potentiometer VR1, resistors R1 and R2 and capacitors C1-C3.

For an explanation of the operation of a Schmitt-trigger pulse generator, see the adjacent panel. Its pulses clock IC2, an up/down binary counter. IC2's outputs are fed to decoder IC3 to light the eight LEDs in sequence.

The outputs of IC3 and the inputs of IC1a, IC1b and IC1c use negative (active-low) logic because IC1 is a NAND gate rather than a NOR gate (see the panel on SR-FFs).

The alternative would have been to use the 74HC7002 Schmitt-trigger NOR gate with a 74HC237 decoder and positive logic, but the 74HC7002 is less common and more expensive than the 74HC132.

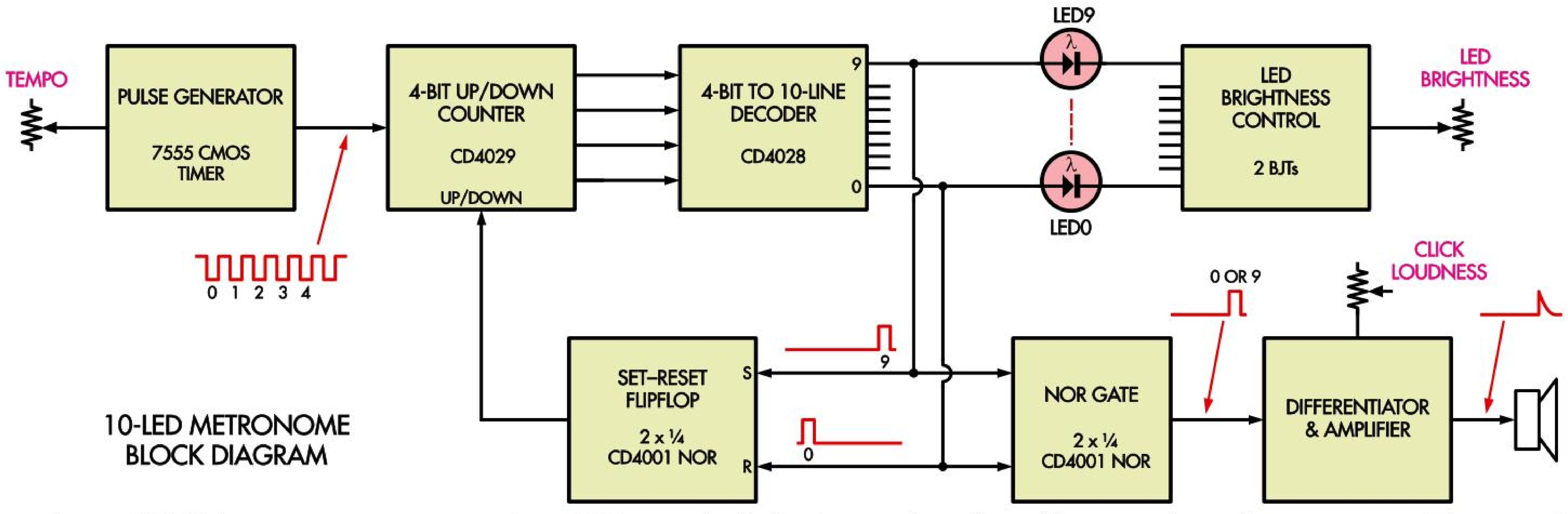


Fig.2: the 10-LED Metronome uses a 555 timer IC instead of a logic-gate-based oscillator as the pulse generator. The remaining logic ICs are from the 4000-series. A 4029 acts as the up/down counter, while a 4028 is the 4-to-10 decoder that drives the LEDs. Two of the gates of the 4001 quad NOR IC form the set-reset flip-flop, and the other two gates form the click pulse.

When IC3 is counting up, it lights each LED in sequence, from LED0 to LED7. When LED7 lights, the low level at pin 7 of IC3 (Y7) is also applied to the SR-FF formed by IC1a and IC1b.

This causes pin 6 of IC1b ($\overline{Q}$) to go high, causing IC2 to reverse its direction and count down. Each LED is now lit in sequence in the opposite direction. When the first LED, LED0, is lit, the SR-FF is reset, IC2 reverses and counts up, and the cycle repeats.

VR2 controls the overall LED brightness. The circuit is designed to make LED0 and LED7 brighter than the others. The relative brightnesses of the end-vs-middle LEDs is maintained as VR2 is adjusted by LED8 or a zener diode, ZD2. Whenever current is applied to LED1-LED6, LED8/ZD2 is in series with that LED, reducing the voltage across the current-limiting resistors and thus the LED current.

VR2 could be changed from 500kΩ to 1MΩ to extend the brightness range down to very dim levels. If you want VR2 to turn the LEDs completely off at minimum, fit R3 (300kΩ), but note that this creates a large 'dead zone' in the lower range of VR2.

LED8 may be the same type as LED0 through LED7, but for more brightness contrast between the end and middle LEDs, use a type with higher forward voltage such as blue or white, or use a zener diode of approximately 4.7V. If you want all LEDs to have equal brightness, fit a wire in place of LED8/ZD2.

Click sounds

When either end LED is lit, the low level at Y0/Y7 is also sent to IC1c, which behaves as a NOR gate when operated in negative logic mode (a low at either input causes a high output). Its output is fed to the Click Loudness control (VR3) and then to a simple transistor amplifier.

However, the pulse from IC1c is too long and would cause a click at the end of the pulse as well as at its beginning, and the current would be high during the pulse on-period. To avoid this, the pulse passes through C4 and/or C5 to yield a short pulse at each end of the original pulse, a positive one at the beginning and a negative one at the end.

Diode D1 shunts the negative pulse so that only the positive pulse is applied to the base of transistor Q1.

Power supply

This design is powered by a battery of four AAA cells. 74HC ICs are used rather than 74HCT or 74LS because the 74HC series allows a slightly higher supply voltage, up to 6V. Fresh standard alkaline AAA cells supply marginally more than 6V, so the voltage rail for the ICs is limited using a 47Ω resistor and a 6V zener diode (ZD1). Alkaline, dry cell, rechargeable NiMH or Li-ion AAA cells can be used.

The 4700µF and 470µF bulk bypass capacitors, in combination with the 47Ω series resistor, reduce the supply voltage pull-down by the click-pulse current through the speaker.

PCB-mounting potentiometers with built-in switches are rare, so a separate power switch is used. A regulated 6V DC plugpack could be used instead of a battery. Make sure you verify it is regulated as otherwise, its output voltage would be too high for the circuit.

The 10-LED version

The circuit for this version is shown in Fig.4. It is similar to the *8-LED* design but positive logic is used throughout. The pulses are generated by CMOS 555 timer IC2. It clocks IC3, a four-bit up/down counter. IC3's outputs are decoded to 10 individual outputs by IC4, lighting the 10 LEDs in sequence.

When an end LED (LED0 or LED9) is lit, the SR-FF formed by IC2a and IC2c is set or reset, thus switching IC3 into up or down mode, reversing the LED sequence.

VR5 controls the LED brightnesses. Instead of the technique used for the *8-LED* design to make the end LEDs brighter, this version uses a current mirror comprising Q1 and Q2 with trimpot VR4, control potentiometer

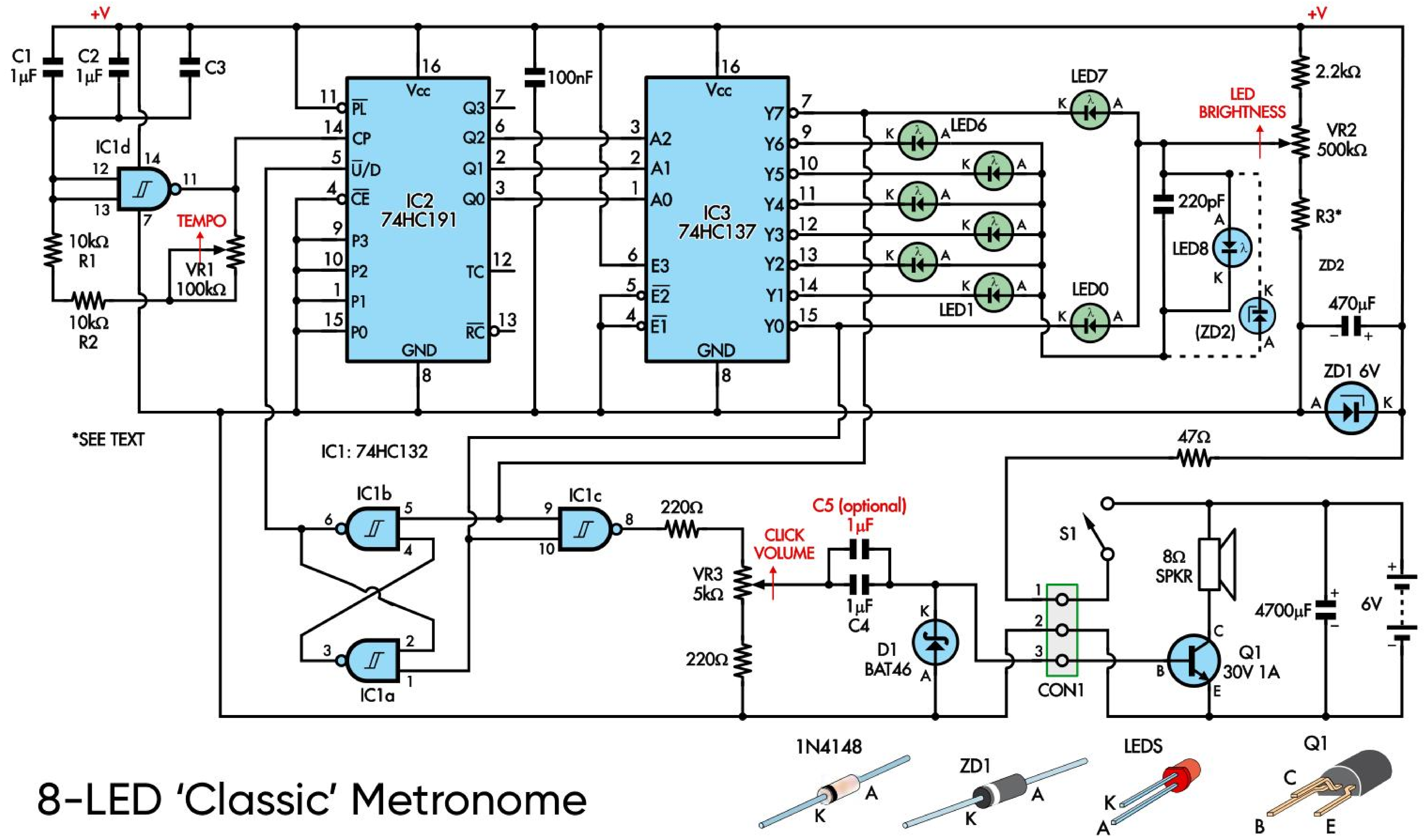


Fig.3: this 8-LED Metronome circuit shows more details than Fig.1. VR2 allows you to set the LED brightness while LED8 or ZD2 reduces the brightness of the middle six LEDs compared to the outer two. Extra capacitors C2-C3 and resistor R2 allow you to adjust the frequency range to match the beats-per-minute (bpm) range shown on the dial. Additional capacitor C5 is provided to change how the clicks sound.

Using a Schmitt-trigger gate as a pulse generator

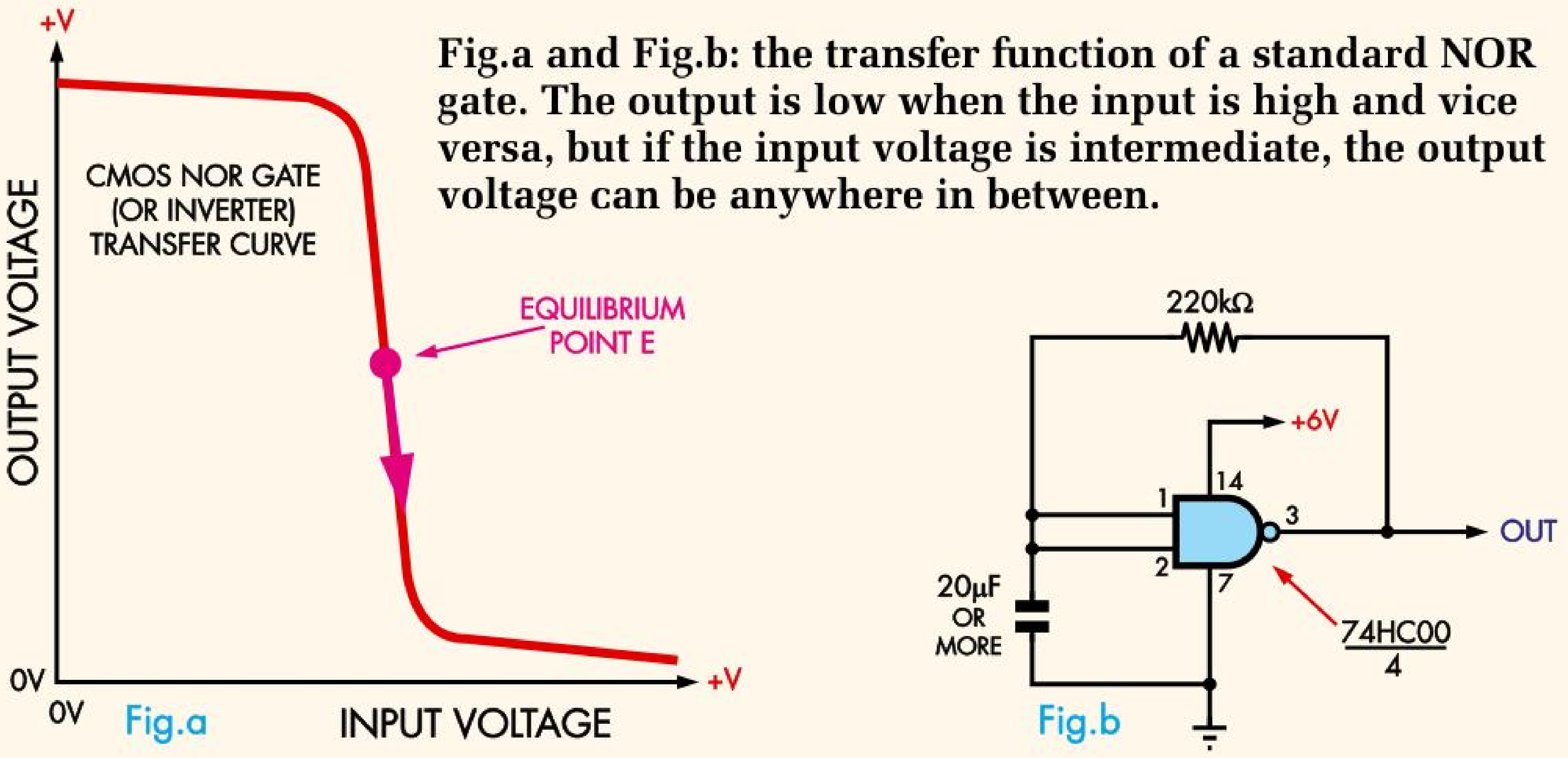

+V
OUTPUT VOLTAGE
CMOS NOR GATE (OR INVERTER) TRANSFER CURVE
EQUILIBRIUM POINT E
0V
0V
INPUT VOLTAGE
+V
Fig.a
220kΩ
+6V
1
14
3
2
7
OUT
20µF OR MORE
74HC00 4
Fig.b

Fig.a and Fig.b: the transfer function of a standard NOR gate. The output is low when the input is high and vice versa, but if the input voltage is intermediate, the output voltage can be anywhere in between.

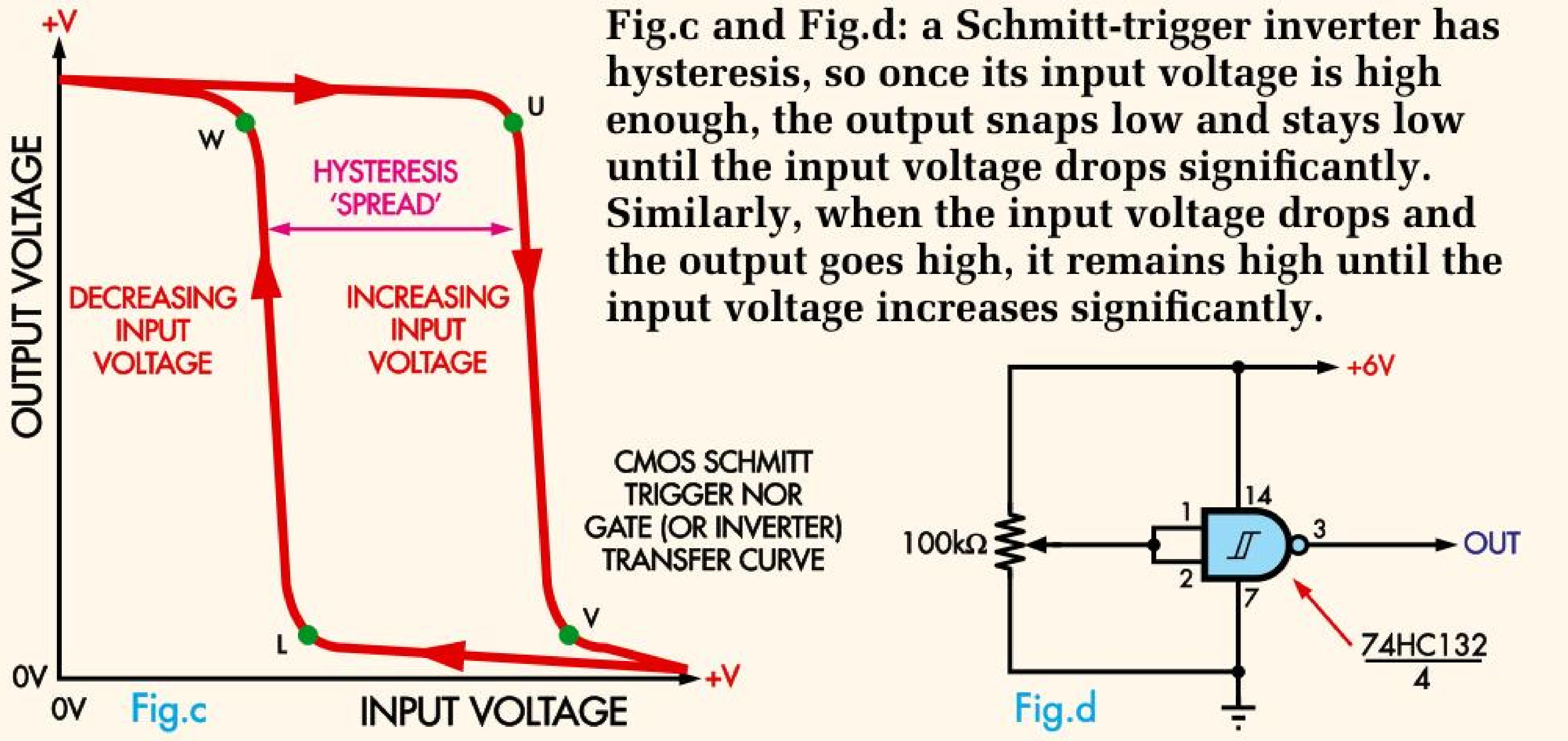

+V
OUTPUT VOLTAGE
W
U
HYSTERESIS 'SPREAD'
DECREASING INPUT VOLTAGE
INCREASING INPUT VOLTAGE
CMOS SCHMITT TRIGGER NOR GATE (OR INVERTER) TRANSFER CURVE
L
V
0V
0V
Fig.c
INPUT VOLTAGE
+V
+6V
100kΩ
1
14
3
2
7
OUT
74HC132 4
Fig.d

Fig.c and Fig.d: a Schmitt-trigger inverter has hysteresis, so once its input voltage is high enough, the output snaps low and stays low until the input voltage drops significantly. Similarly, when the input voltage drops and the output goes high, it remains high until the input voltage increases significantly.

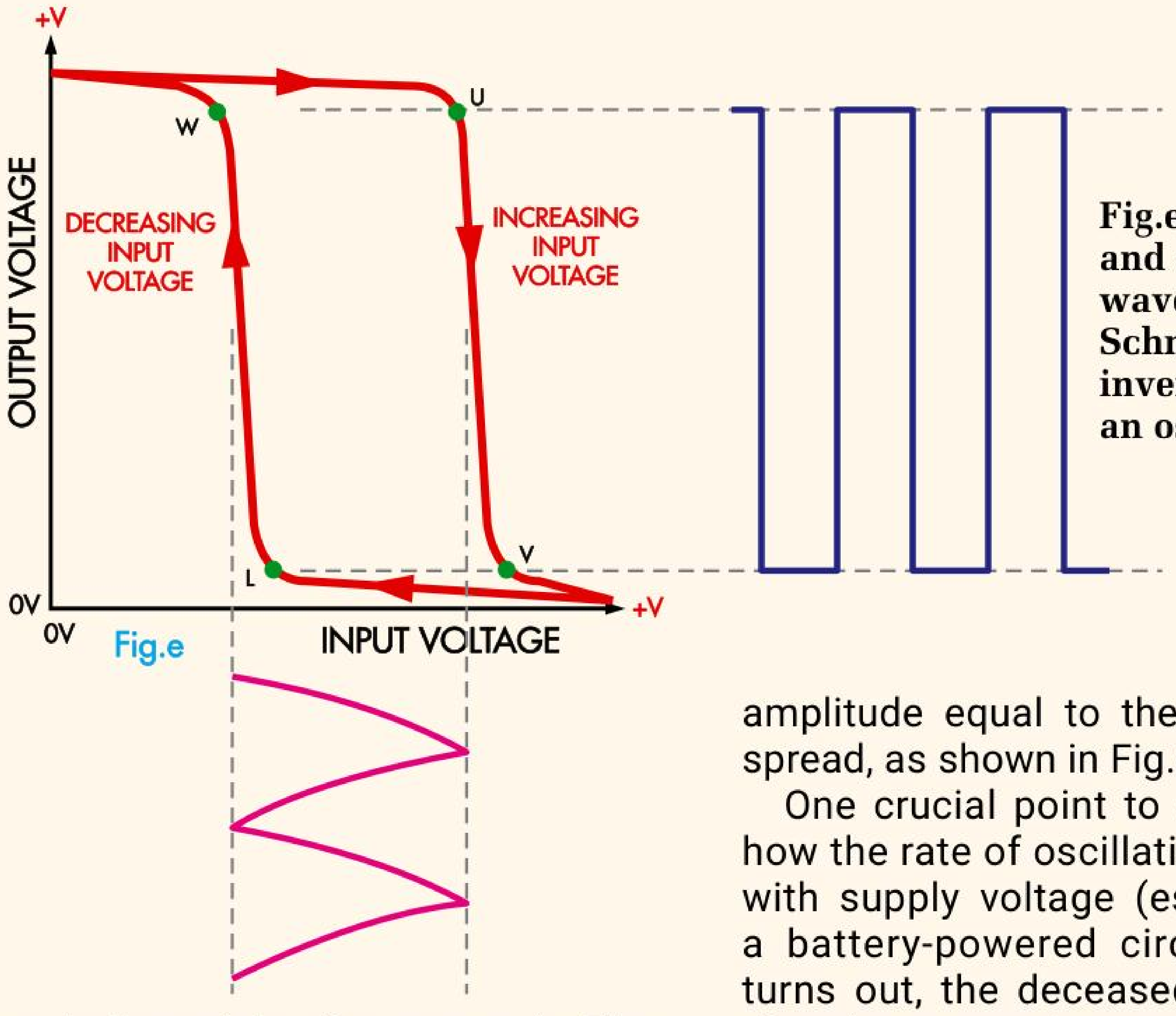

+V
OUTPUT VOLTAGE
W
U
DECREASING INPUT VOLTAGE
INCREASING INPUT VOLTAGE
L
V
0V
0V
Fig.e
INPUT VOLTAGE
+V

Fig.e: the input and output waveforms for a Schmitt-trigger inverter used as an oscillator.

Gate IC1d of the 74HC132 Schmitt-trigger input NAND chip generates the pulses that clock the counter (IC2). So what is a Schmitt-trigger gate, and why are we using one?

An 'ordinary' non-Schmitt-trigger gate or inverter is effectively a high-gain but mostly linear amplifier. As a result, the output transition from high-to-low or low-to-high takes place over a narrow input voltage range, as shown in Fig.a, which is a plot of output voltage versus input voltage.

Consider, the negative-feedback RC circuit shown in Fig.b. It will typically reach equilibrium at some point (E), with the output 'stuck' at an intermediate voltage. If the input were to increase in voltage, as indicated by the arrow, the output would respond by decreasing and would restore the circuit to point E with a time constant determined by R and C. The reverse is true if the input voltage decreases.

You can test this yourself on a breadboard if you have a spare 74HC00 NAND gate chip. Just remember to connect all the unused inputs to one supply rail or the other. A DVM will show that the voltage at pin 3 is stable.

In contrast, the Schmitt-trigger version of the gate ensures oscillation due to its built-in hysteresis and associated positive feedback. This is illustrated in Fig.c, which is an equivalent plot to Fig.a but for a gate with Schmitt-trigger inputs.

Once the input voltage increases above the upper-threshold input voltage (VT+, point U), the output immediately 'snaps' to a low level (point V). It remains there until the input decreases below the lower-threshold input voltage (VT−, point L) and the output 'snaps' high (point W).

This can be demonstrated by breadboarding the circuit shown in Fig.d. Begin with the pot at extreme clockwise (pins 1 and 2 at +6V) and apply power. The LED should remain off. Slowly decrease the input voltage via the pot until the LED goes on; note the input voltage. Now increase the input voltage gradually until the LED goes off. There should be a couple of volts difference; this is the hysteresis spread ($V_{T+} - V_{T-}$).

You have made one clockwise trip around the hysteresis rectangle, as indicated by the arrows in Fig.c. Because of this, if you substitute a Schmitt-trigger 74HC132 for the 74HC00 in Fig.b, you will find that it oscillates, generating a square wave at the output. The input exhibits an exponential pseudo-triangle wave of amplitude equal to the hysteresis spread, as shown in Fig.e.

One crucial point to consider is how the rate of oscillation will vary with supply voltage (especially in a battery-powered circuit). As it turns out, the deceased capacitor charging current is somewhat compensated by the decrease in hysteresis spread (as it is somewhat proportional to the IC's supply voltage). Thus, the pulse rate only changes by a few percent from 6V to 5.5V (an 8% change in voltage).

VR5 and some fixed resistors. VR4 adjusts the brightness of the middle LEDs relative to the brightness of the two end LEDs. See the adjacent panel for an explanation of how this works.

Click generation and circuit variations are the same as for the *8-LED Metronome* design. The higher supply voltage of this version provides a louder click.

Construction

Fig.5 is the PCB layout diagram for the *8-LED version*, while Fig.6 is for the *10-LED version*. Most components mount on the boards. A few might need their values tweaked; that is why some parts do not have an associated value. PCBs for each version are available from the *PE PCB Service*.

Whichever version you build, the construction process is initially similar. Start by fitting all the resistors with fixed values given, using a DMM to check the values before soldering them in place.

Follow with the diode(s), ensuring their cathode stripes face as shown in the appropriate overlay diagram and that you don't get the different types mixed up. Remember that for the *8-LED* version, you either fit zener diode ZD2 or LED8, not both. If using LED8, push it down onto the board with the longer lead to the pad marked A and then solder it in place.

The ICs are next. They can be soldered directly to the PCB or plugged in via sockets; it's up to you. Either way, make sure the pin 1 notches/dots face as shown and don't get the two different 16-pin ICs mixed up. Note that IC3 on the 8-LED board (74HC137) is oriented opposite to the other two ICs.

Fit the capacitors next, starting with the smaller non-polarised types and then moving onto the electrolytic capacitors, which must be oriented with their longer positive leads placed towards the + symbols. The 1000µF capacitor on the *10-LED* board is laid over as shown before soldering and trimming its leads. As with the resistors, leave off any that don't have values indicated as those pads are for tuning later.

There are no trimpots or discrete transistors on the *8-LED board*. However, on the *10-LED* board there are three trimpots: two 5kΩ (VR1 and VR3) and one 100kΩ (VR4); as well as two PNP transistors (Q1 and Q2) and one NPN transistor (Q3). Fit them now, being careful not to get the different types of transistors mixed up. If your Q3 transistor is taller than the others, bend its leads so that it is laid over on its side before soldering to ensure sufficient clearance for the front panel later.

Note that the PCB has footprints to accommodate different types of transistors from those specified. However, assuming you are using the BC558 suggested in the parts list, they are placed as shown in Fig.6.

Both boards use a 3-way terminal block for power, although you can solder wires to its pads instead. If fitting it, do that next, with the wires entering the front of the board and passing around to the rear via the notch on the edge of the board.

Continue by selecting the LEDs you are going to use. You might wish to order extras so that you can pick out a matched set from the larger number. Note that it's common for their brightnesses to look similar when fairly bright, but at very low currents (say around 30µA), they can vary considerably when dim. Try to select the ones which match best for the middle LEDs.

If you have a bench supply, one good way to compare the brightness

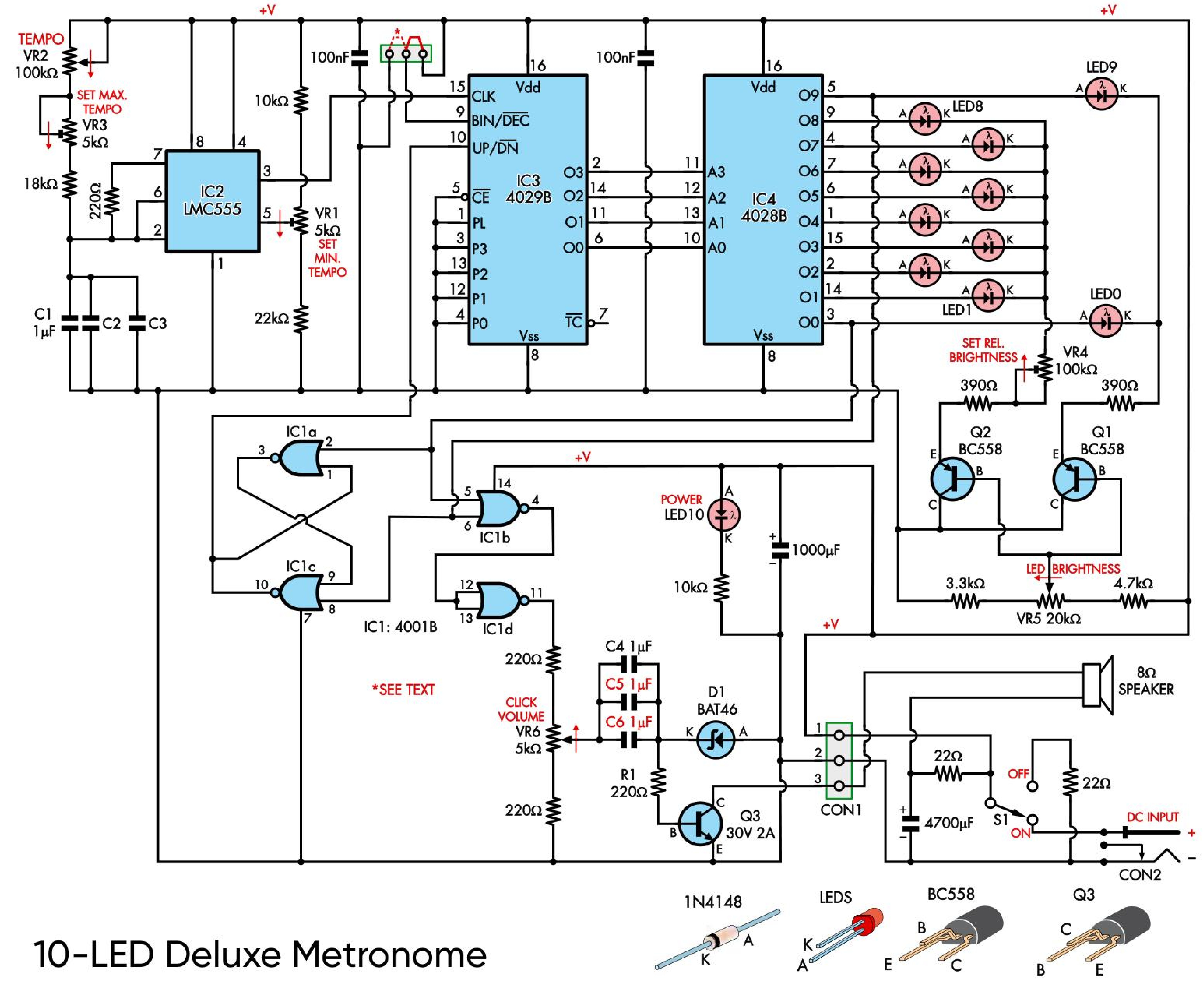

10-LED Deluxe Metronome
+V
TEMPO
VR2
100kΩ
SET MAX. TEMPO
VR3
5kΩ
18kΩ
220Ω
C1
1µF
C2
C3
IC2
LMC555
10kΩ
VR1
5kΩ
SET MIN. TEMPO
22kΩ
100nF
*
IC3
4029B
CLK
BIN/DEC
UP/DN
CE
PL
P3
P2
P1
P0
Vdd
Vss
TC
O3
O2
O1
O0
IC4
4028B
A3
A2
A1
A0
O9
O8
O7
O6
O5
O4
O3
O2
O1
O0
LED9
LED8
LED1
LED0
SET REL. BRIGHTNESS
VR4
100kΩ
390Ω
390Ω
Q2
BC558
Q1
BC558
LED BRIGHTNESS
3.3kΩ
4.7kΩ
VR5 20kΩ
IC1a
IC1b
IC1c
IC1d
IC1: 4001B
POWER
LED10
1000µF
10kΩ
*SEE TEXT
220Ω
CLICK VOLUME
VR6
5kΩ
220Ω
C4 1µF
C5 1µF
C6 1µF
D1
BAT46
R1
220Ω
Q3
30V 2A
CON1
8Ω SPEAKER
22Ω
22Ω
4700µF
OFF
S1
ON
DC INPUT
CON2
1N4148
LEDS
BC558
Q3
A
K
B
E
C

Fig.4: the 10-LED Metronome uses a more complicated LED brightness control scheme with PNP transistors Q1 and Q2 forming a current mirror, so the brightnesses of the middle eight and outer two LEDs track over a wide adjustment range. LED10 lights up the beats-per-minute adjustment dial. Besides these differences, and using a CMOS 555 timer as the pulse generator, the circuit is quite similar to the 8-LED version.

How a current mirror works

A current mirror circuit is used to match two or possibly more currents under varying conditions. Fig.f shows a basic example; similar NPN bipolar transistors Q1 and Q2 have their bases tied together and set at a control voltage, V_B. Thus, their emitters will be at equal voltages, approximately 0.6V lower than V_B.

If the emitter resistors, R1 and R2, are of equal resistance, they will conduct equal currents of approximately $I_C = (V_B - 0.6V) \div R$.

Assuming a sufficiently high current gain (>≈100) for the transistors, and thus negligible base currents, the collector current of each BJT would be the same as its emitter current; in other words, the currents through LOAD 1 and LOAD 2 would be matched. If the base voltage (V_B) is varied, the emitter and collector currents will vary, but will remain matched between the two transistors.

Likewise, if one or both loads vary in resistance – within limits – their currents will still be equal and given by the equation above.

For the brightness control of the 10-LED Metronome, we want the current to the middle LEDs to be a fraction of the current to the end LEDs, and to be the same fraction over a wide range of currents. If we used the above scheme, the circuit would be something like Fig.g, with R being a fraction of VR + R, ie, unequal emitter resistors.

However, there is a problem with this: since each group of LEDs is alternately turned off, that load resistance becomes extremely high. As a result, the transistor in the off leg of the circuit has no collector current, and the base current becomes large because the base-emitter junction is a forward-biased diode. This reduces the base voltage, and thus the collector current of the other transistor.

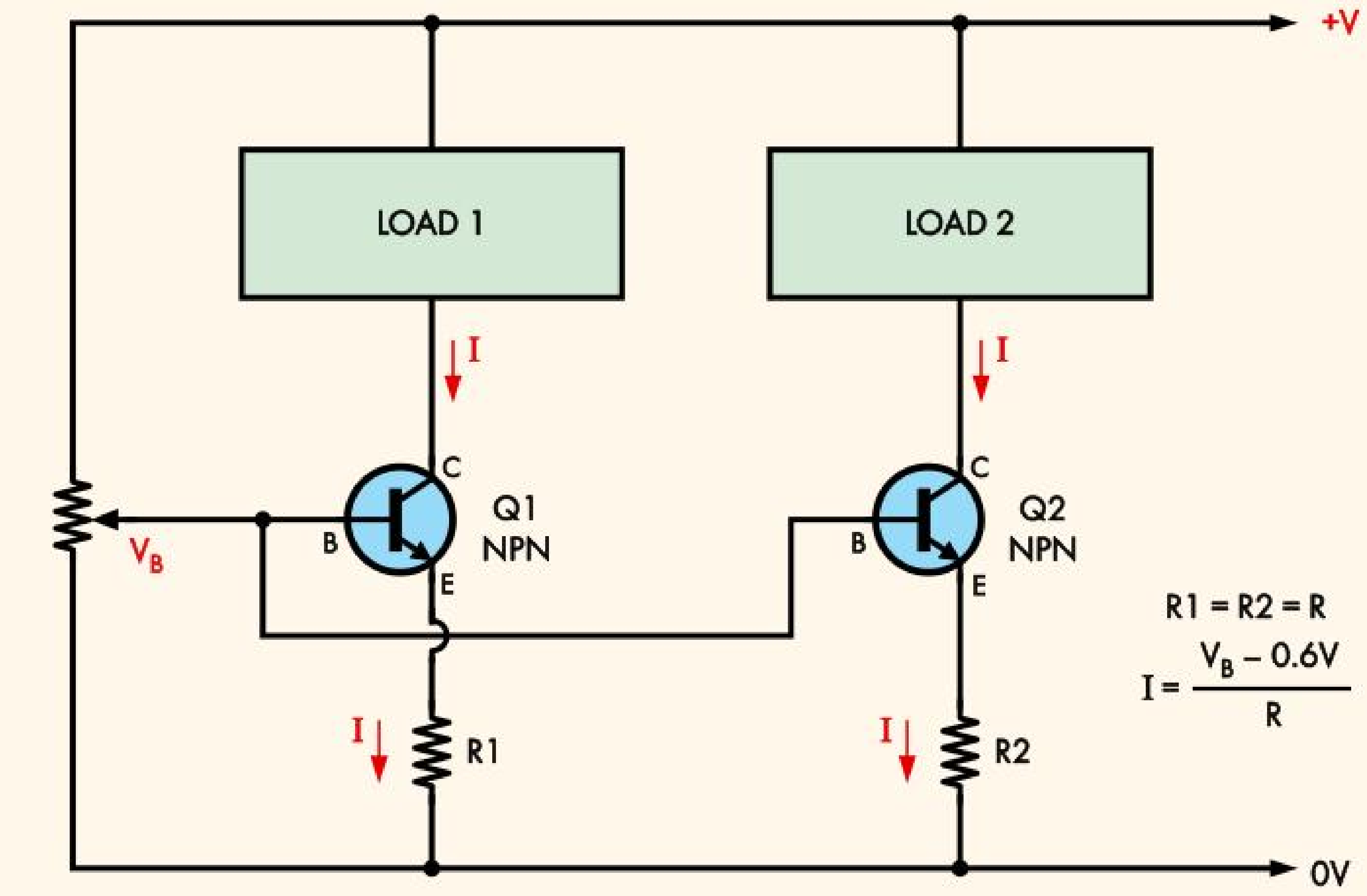
For example, Fig.g shows one of the middle LEDs on, while the end LEDs are both off, resulting in high base current through their transistor (Q2).

To avoid this, I devised a different scheme for the 10-LED Metronome, shown in Fig.h. This works because the two loads are, in practice, nearly constant and equal, each consisting of one LED at a time.

The current-mirror circuit is turned on its head, using PNP transistors rather than NPN. Each group of LEDs is made part of an emitter circuit, in series with a resistor that will determine its current and relative brightness.

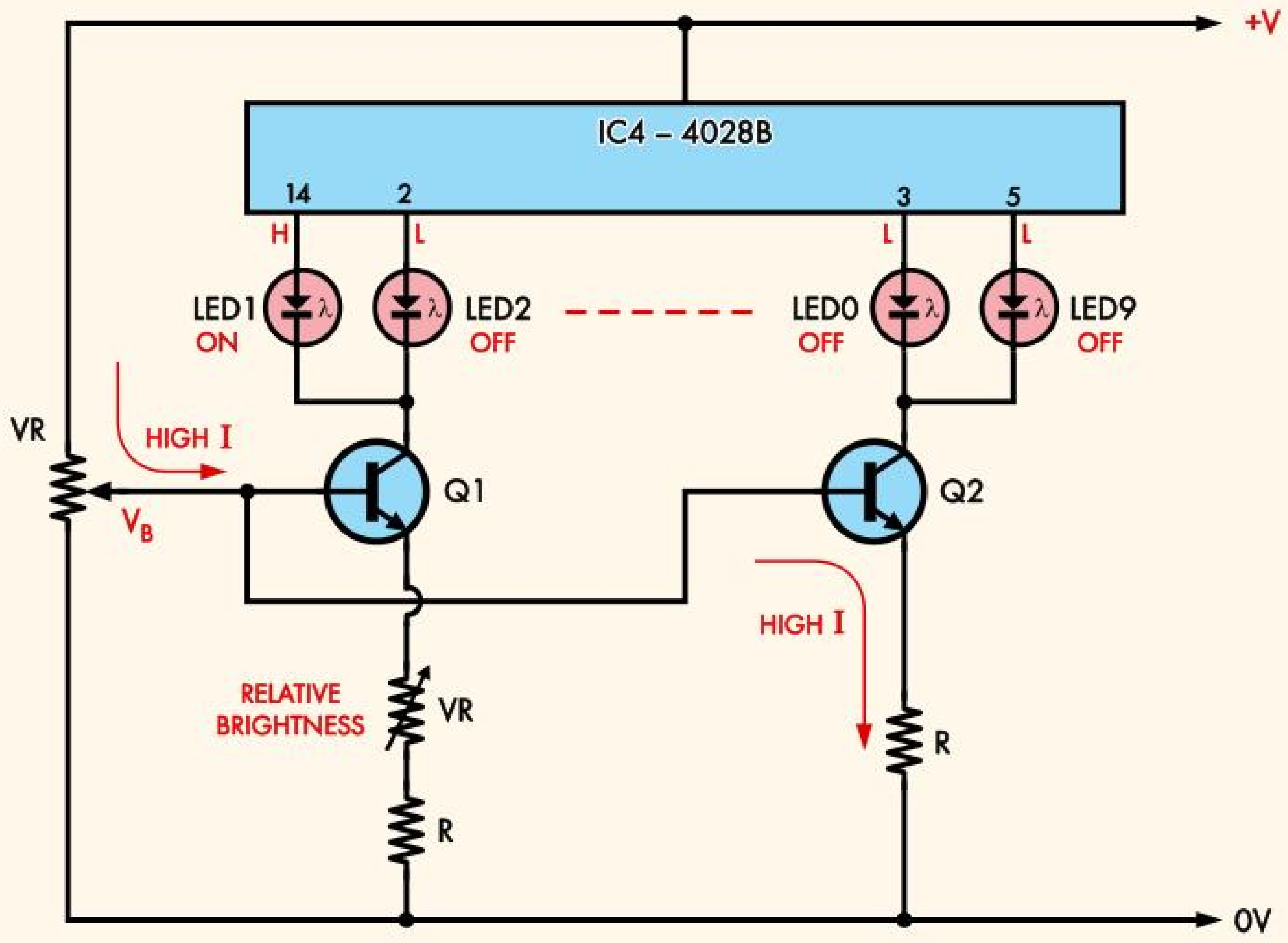
When lit in sequence, each middle LED is in series with R1 + VR4, which is made larger than R2 in series with each end LED. The collector current of Q1 will be a fraction of that of Q2 (R2 ÷ [R1 + VR4]). This fraction — the ratio of currents — will be maintained over a range of V_B as controlled by VR5, and thus the brightnesses of the eight middle LEDs will be a fraction of the brightnesses of the two end LEDs over a wide range.

This situation will break down if V_B is above $12V - V_{LED} - 0.6V$ or about 10V. This is avoided by padding the ends of VR5 with fixed resistors. Trimpot VR4 allows the resistance ratio R2 ÷ [R1 + VR4] to be set as desired, thus setting the brightness difference.



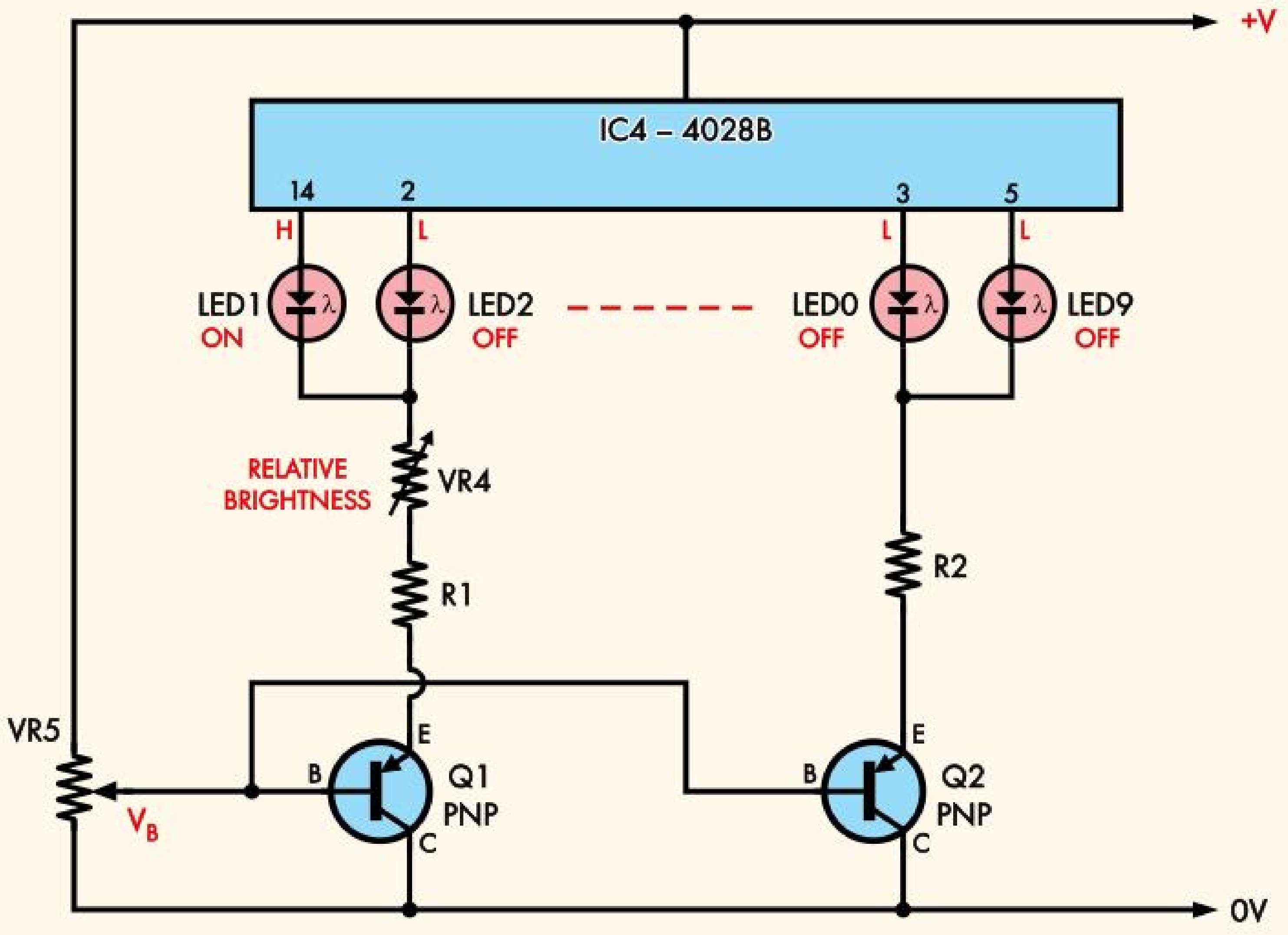
A: A BASIC CURRENT MIRROR CIRCUIT

Fig.f: a basic current mirror circuit. Since Q1 and Q2 are similar transistors, and thanks to the negative feedback provided by the emitter resistors, varying their base voltages using the potentiometer results in closely matched currents through the two independent loads.



B: WHY THE SCHEME IN (A) DOESN'T WORK FOR TWO GROUPS OF LEDS

Fig.g: different emitter resistor values can be used to make the load currents different, but they keep similar current ratios when the base voltage is varied.



C : MODIFIED CURRENT MIRROR FOR THE 4000 VERSION METRONOME

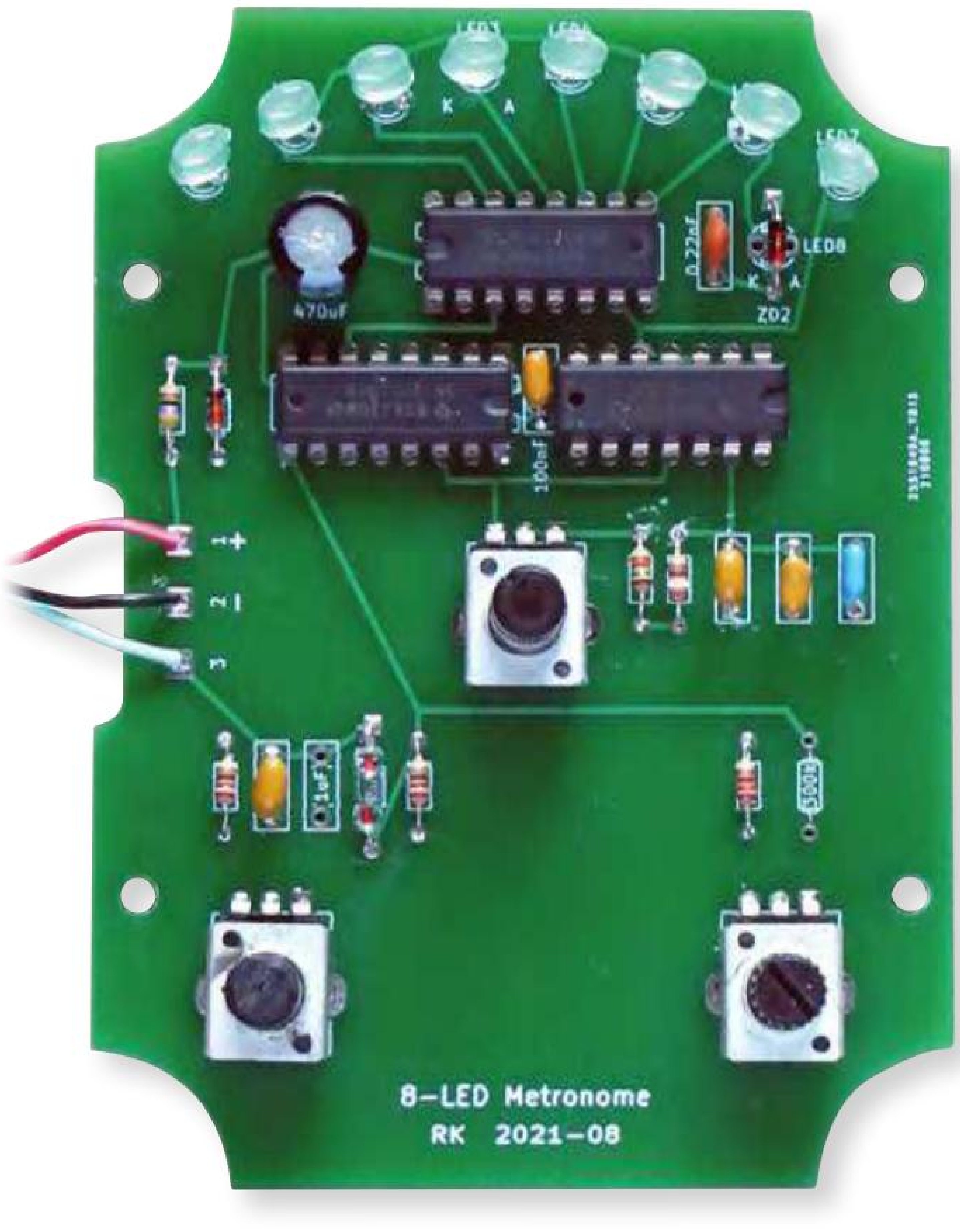
Fig.h: the circuit shown in Fig.g can suffer from excessive base current problems when the loads can be switched on and off independently. This circuit solves that by swapping the NPN transistors for PNP and keeping the current-setting resistor connections at the transistor emitters.

is to connect several in series, along with an appropriate current-limiting resistor, then power the entire string from the bench supply and slowly wind its voltage up. That way, you can make a direct comparison of several candidate LEDs over a useful range of brightnesses.

The construction approach now diverges for the two versions.

Finishing the 8-LED Metronome

Measure the resistance across VR1's track (from one end pin to the other) and divide the reading by five. This is the value you should aim for with R1 + R2.


LED3
LED4
K
A
LED7
LED8
ZD2
470uF
1
2
3
8-LED Metronome
RK 2021-08

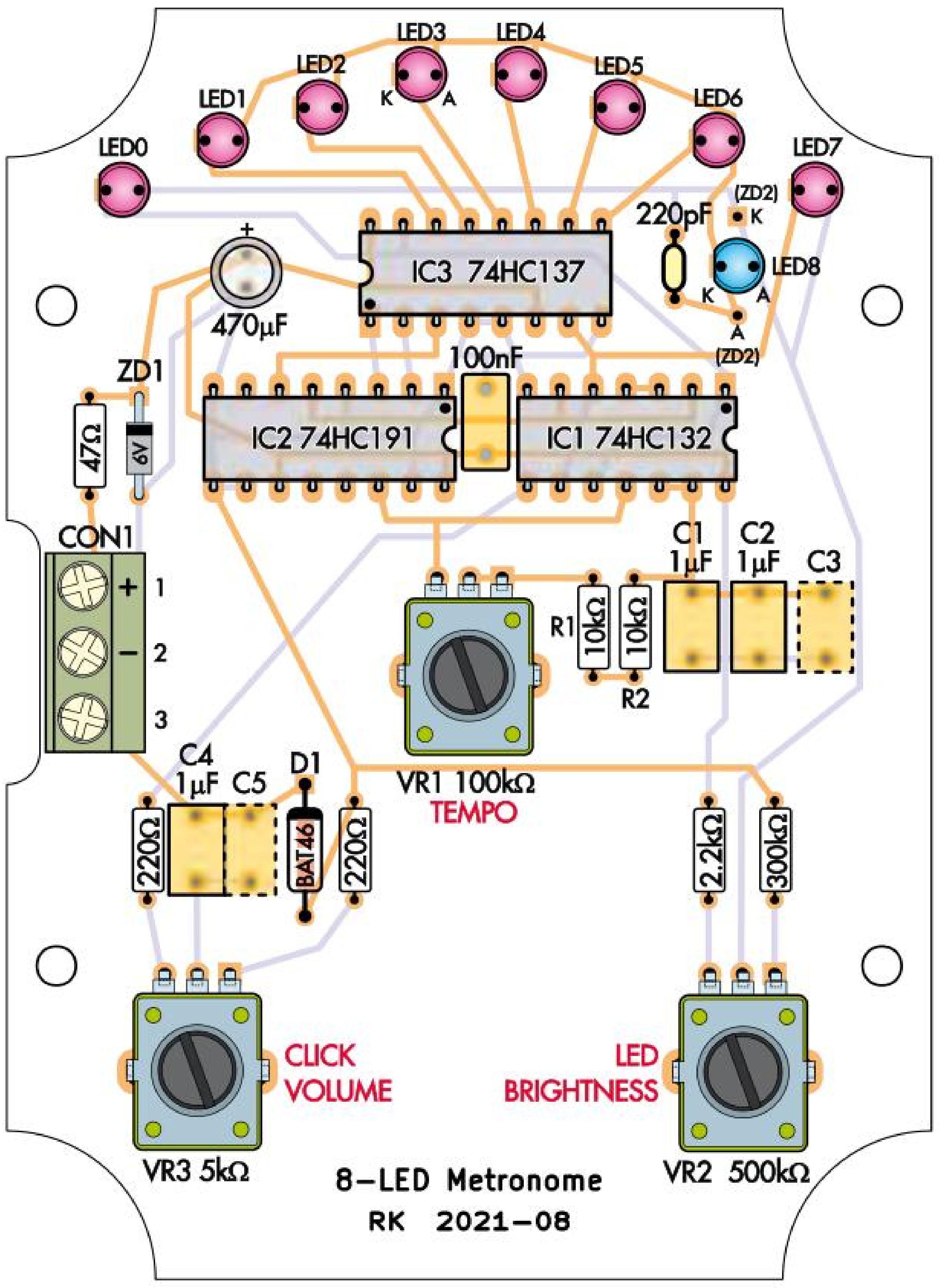

LED0
LED1
LED2
LED3
LED4
LED5
LED6
LED7
LED8
K
A
(ZD2)
220pF
IC3 74HC137
470μF
100nF
ZD1
47Ω
6V
IC2 74HC191
IC1 74HC132
CON1
+
–
1
2
3
C1 1μF
C2 1μF
C3
R1
10kΩ
10kΩ
R2
C4 1μF
C5
D1
BAT46
220Ω
220Ω
VR1 100kΩ
TEMPO
2.2kΩ
300kΩ
CLICK VOLUME
LED BRIGHTNESS
VR3 5kΩ
VR2 500kΩ
8-LED Metronome
RK 2021-08

Fig.5: most of the 8-LED Metronome components mount on the PCB, as shown here. Assembly is straightforward but be careful to orientate the ICs, LEDs and diodes as shown. Also, don't get the potentiometers mixed up as they all have different values (check the codes printed on their bodies).

We've specified two 10kΩ resistors in the parts list because VR1 should be close to 100kΩ.

If VR1 does not measure close to 100kΩ, vary the values of one or both of those 10kΩ resistors (eg, changing one to 9.1kΩ or 11kΩ) to get their total as close as possible to 20% of VR1's value.

The 8-LED version fits in a Serpac 131-BK plastic enclosure, but other enclosures could be used instead. If using the 131-BK, use the side with the best appearance as the upper end. After selecting the LEDs, drill the LED and potentiometer holes in the front half of the enclosure. Fig.7 may be used as a drilling template.

You can print the guide onto card stock, punch out the mounting holes to 5mm and temporarily glue the guide to the inside of the front half of the enclosure.

If using the recommended oval LEDs, you will need to carefully elongate the holes after drilling. Note that the illuminated line from an oval LED is perpendicular to the larger dimension of the LED body. Decide which orientation you want and orient the LEDs and holes accordingly. When drilling or adjusting the LED holes, check that the LEDs fit into the holes snugly but do not require excessive insertion force.

Fit the three pots to the PCB without soldering them, and attach the PCB to the front of the enclosure. I removed the small protruding bits on the front of each pot. To allow space for the components on the PCB, you might need spacers on the screws. Check the shaft lengths and shorten them as needed for your knobs.

The shaft-gripping sections of the knobs that I used were recessed by several mm. So for pots VR2 and VR3, I sanded down the backs of the knobs to about 12.5mm total height to enable the knobs to grip the shorter pot shafts adequately.

If the knobs are not tight enough, the plastic shafts of the potentiometers can be deformed a little by pinching them with pliers. Solder the three pots now, after re-checking they have the correct values.

Next, paying close attention to their orientations (see the A and K markings on the PCB), insert the LED leads into the board without soldering them. If using oval LEDs, they will need to be twisted slightly to conform to the arc.

Again, attach the PCB to the front half of the enclosure and manoeuvre each LED into its proper hole in the front of the enclosure. It's best to have them protruding slightly. Check the LEDs' appearance and adjust as necessary, then solder the LEDs to the PCB while it is in place. The LEDs

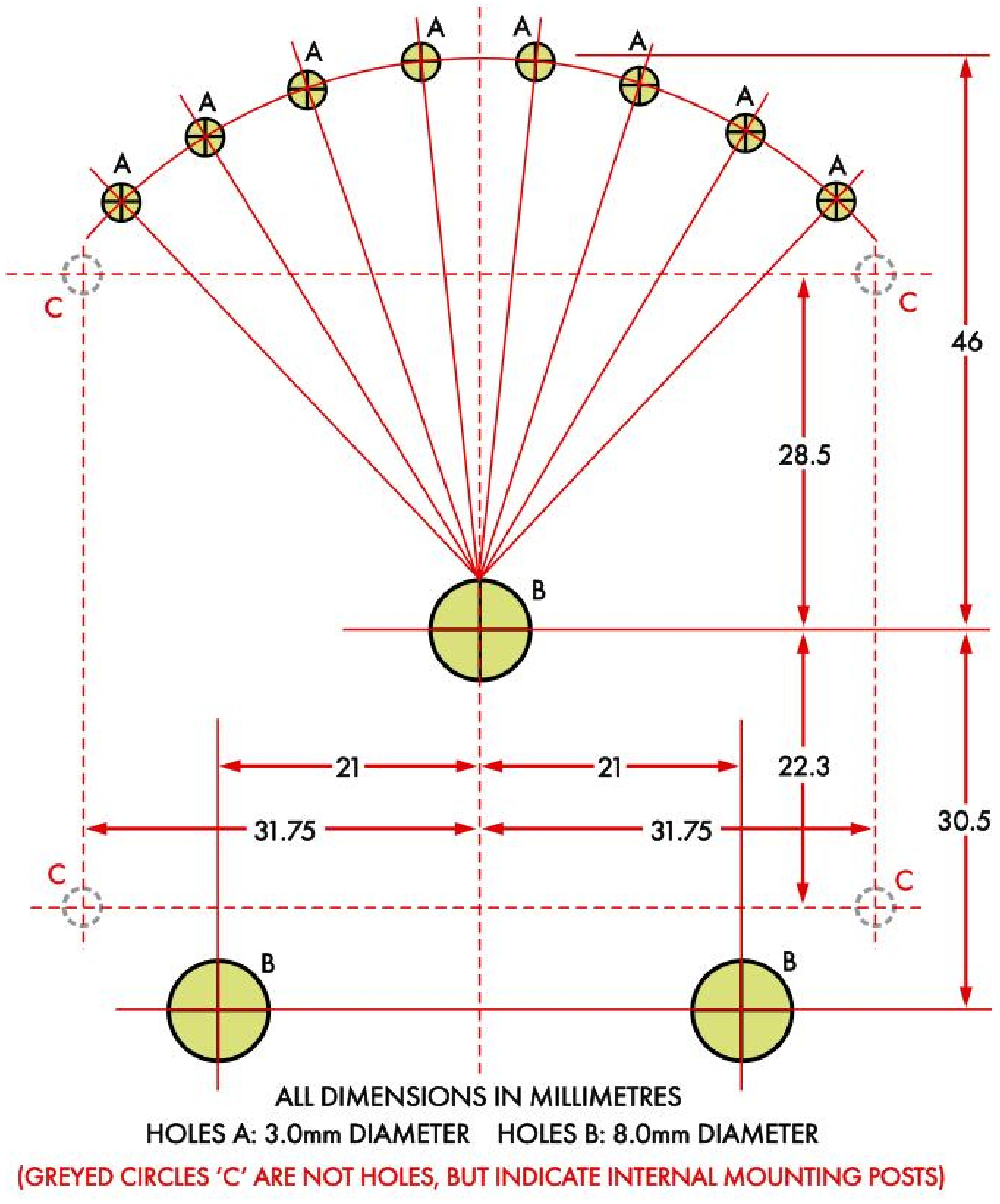

A
A
A
A
A
A
A
A
C
C
C
C
B
B
B
46
28.5
22.3
30.5
21
21
31.75
31.75
ALL DIMENSIONS IN MILLIMETRES
HOLES A: 3.0mm DIAMETER HOLES B: 8.0mm DIAMETER
(GREYED CIRCLES 'C' ARE NOT HOLES, BUT INDICATE INTERNAL MOUNTING POSTS)

Fig.7: a drilling template for the front panel of the 8-LED version. Eleven holes need to be drilled: eight for the LEDs (size and shape to suit the LEDs you are using, marked 'A') and three 8mm holes for the potentiometer shafts, marked 'B'. The dashed circles show the positions of mounting posts within the specified case; do not drill those.

While we specify 3mm diameter holes for 'A', the size will depend on what type of LEDs you are using.

This is available to download as a PDF from the January 2023 page of the PE website (https://bit.ly/pe-downloads

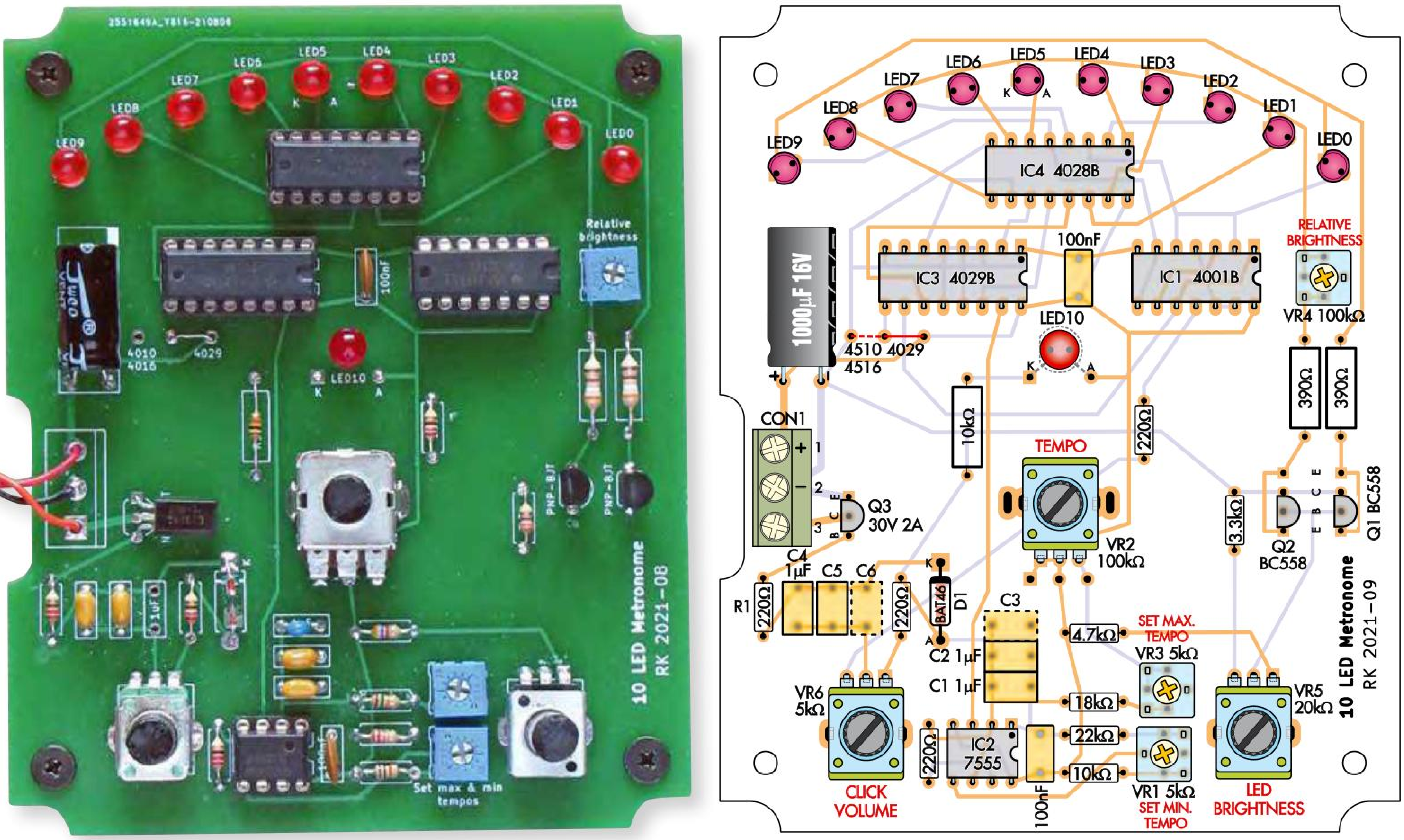

LED9
LED8
LED7
LED6
LED5
LED4
LED3
LED2
LED1
LED0
K
A
IC4 4028B
100nF
IC3 4029B
IC1 4001B
RELATIVE BRIGHTNESS
VR4 100kΩ
1000µF 16V
4510 4029
4516
LED10
10kΩ
220Ω
390Ω
390Ω
CON1
+ 1
– 2
3
Q3
30V 2A
TEMPO
VR2
100kΩ
3.3kΩ
Q2
BC558
Q1 BC558
E B C
C4
1µF
C5
C6
R1
220Ω
220Ω
D1
BAT46
C3
C2 1µF
C1 1µF
4.7kΩ
SET MAX. TEMPO
VR3 5kΩ
VR6
5kΩ
18kΩ
22kΩ
10kΩ
IC2
7555
220Ω
100nF
VR1 5kΩ
SET MIN. TEMPO
VR5
20kΩ
CLICK VOLUME
LED BRIGHTNESS
10 LED Metronome
RK 2021-09
Relative brightness
10 LED Metronome
RK 2021-08
Set max & min tempos
PNP-BJT

Fig.6: the 10-LED Metronome is slightly more complicated than the 8-LED version. Note the components laid on their sides and make sure to place the transistors in the positions shown, unless you are substituting those with a different pinout.

will probably not be seated on the PCB but spaced away from it by several millimetres.

Fig.8 is the tempo dial; this can be downloaded from the January 2023 page of the *PE* website (**https://bit.ly/pe-downloads**). It is a good idea to print it on photo paper for a good appearance. This assumes that VR1 is equivalent to the type specified in the parts list; it needs to rotate through a 280° arc.

Align the dial to the tempo pot shaft and glue it to the front of the enclosure. Fit the knob to the tempo pot such that its rotation extends equally beyond the 36 and 216 tempo lines; this is because pots typically have a dead zone at each extreme where the resistance changes very little.

NPN transistor Q1, the 4700µF capacitor, switch S1, the speaker and the battery holder are not mounted on the PCB but attached to the rear half of the enclosure (see the photo). The

Set-reset flip-flops (SR-FF)

Both Metronome designs incorporate a set/reset flip-flop (SR-FF), a logic circuit with two states: set and reset. Applying a high level to the S input while keeping the R input low puts the flip-flop into the set state, and it remains there until reset. Similarly, applying a high level to the R input while keeping the S input low puts the SR-FF into the reset state, staying there until set again.

By today's naming standards, the SR-FF is a transparent latch and not a flip-flop as it has no clock input, but the traditional term 'flip-flop' continues to be used. Another way of thinking of it is as a 1-bit memory store or a bistable circuit.

An SR-FF is a simple type of sequential logic circuit, which means that its output depends on its 'history'; it has a memory. Compare this to combinatorial logic in which the outputs depend only on the value of the inputs; there is no history or memory involved.

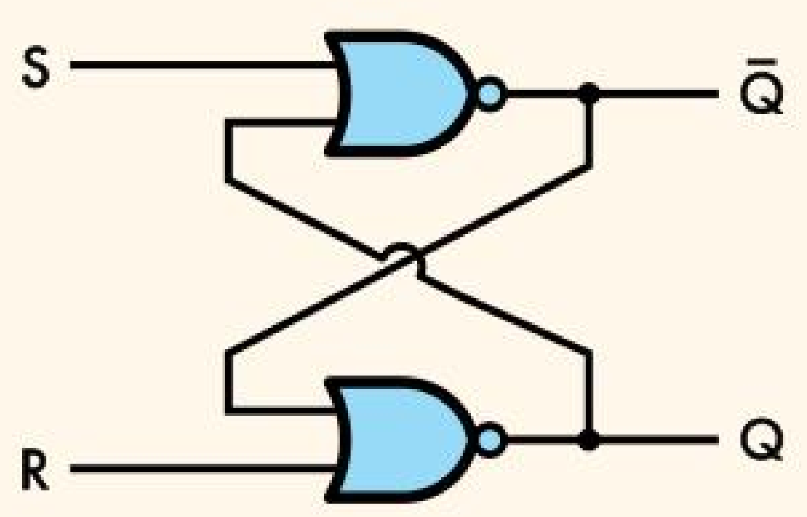
An SR-FF can be made from two NOR gates, as shown in the adjacent diagram, or you can get dedicated flip-flop ICs. In the 10-LED Metronome, we're already using NOR gates for other purposes, so doing it this way avoids the need for an extra IC.

It works as follows. Imagine that both the S and R inputs are low. The circuit can initially be in either state: set, with Q high and $\overline{Q}$ low, or reset, vice versa. Pulsing S high will cause $\overline{Q}$ to go low or to stay low, which will cause Q to go high, which is the set state. Further pulsing of S will have no effect since Q holds the upper NOR-gate input high, assuming that R remains low.

Similarly, pulsing R will cause Q to go low and thus $\overline{Q}$ to go high, which is the reset state. Further pulsing of R will have no effect, assuming that S remains low.

For the 8-LED Metronome, the SR-FF is constructed from two NAND gates rather than NOR gates. All this means is that the SR-FF uses negative logic; in negative logic, NAND gates become NOR gates, and the SR-FF is set and reset by negative (low) pulses, specifically, from LED7 (set) and LED0 (reset). The SR-FF $\overline{Q}$ output is sent to the 74HC191 counter to change its counting direction.

The 10-LED Metronome has an SR-FF, constructed from two NOR gates in the CD4001. Positive logic is used, and the SR-FF operates as described above.


S
$\overline{Q}$
R
Q

A set-reset flip-flop (SR-FF) made from two NOR gates. The Q and $\overline{Q}$ outputs always have opposite polarity; Q is brought high when the S input goes high, while Q goes low when the R input goes high. Both inputs must not be high at the same time.

speaker holes may be in any pattern. I used a perforated metal sheet, selected a drill bit of the diameter of its holes, clamped the sheet to the inside of the rear half of the enclosure and used it as a drilling guide.

Attach the slide switch to the panel using small screws and nuts. The battery holder and speaker are held in place with clips made from a large, heavy-duty paper clip.

Q1 and the 4700µF capacitor are mounted close to the speaker and wired directly to the speaker terminals to minimise parasitic resistances; they are not switched by S1, likewise to reduce parasitic resistance. This can be important since the supply voltage is relatively low and the speaker impedance is 8Ω.

When the *Metronome* is switched off, there will be only a minuscule leakage current through these components. However, if the *Metronome* is unused for an extended period, it's best to remove the cells.

Solder the emitter lead of transistor Q1, the negative lead of the capacitor, and a wire to a solder lug before fitting them to the enclosure. Check the wiring of these components carefully: a mistake can cause excessive current and damage Q1 or cook the speaker coil and cone.

Cut a timber base to suit the enclosure and attach the rear half to it using screws, giving the enclosure a slight backward tilt.

Finally, attach the off-PCB parts to the 3-way terminal block, as shown in the photos. If you don't want to use a terminal block, you can solder the wires directly to the PCB pads.

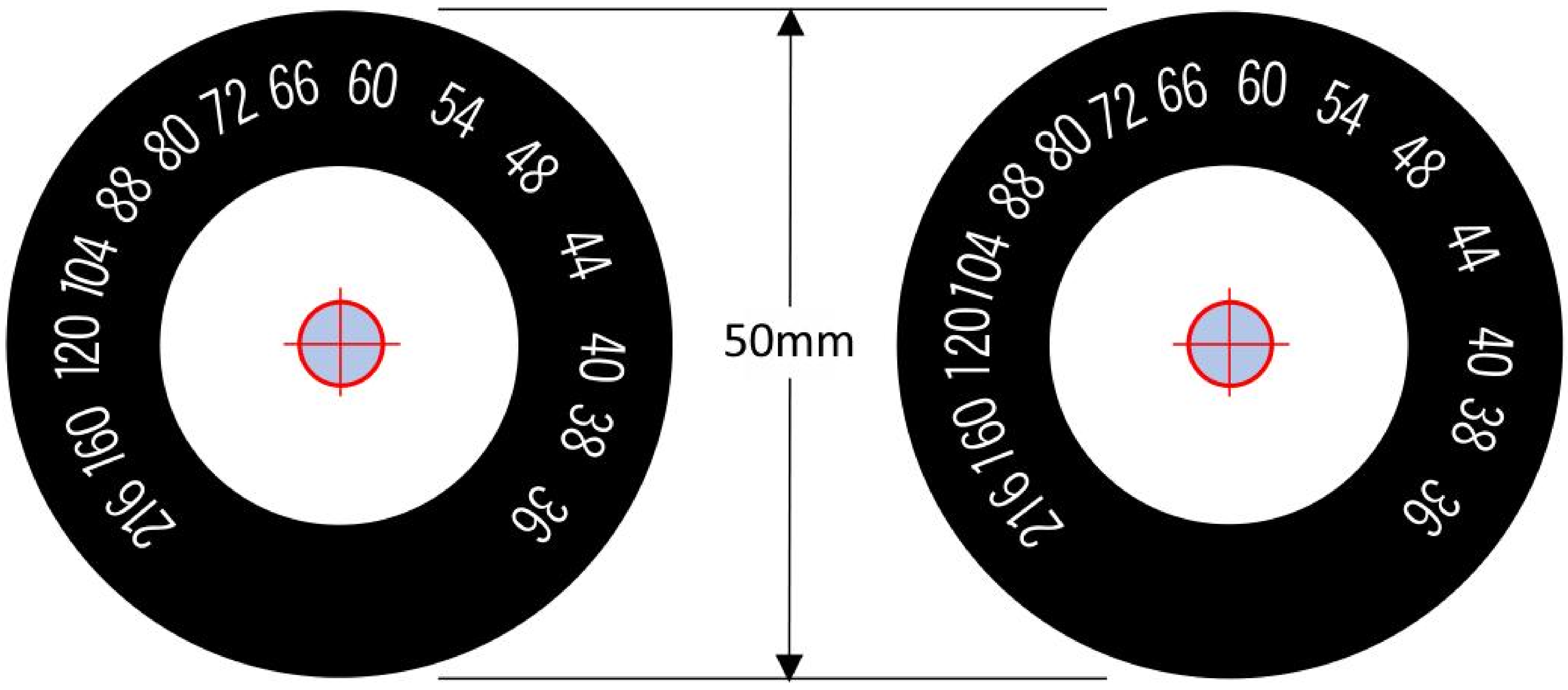
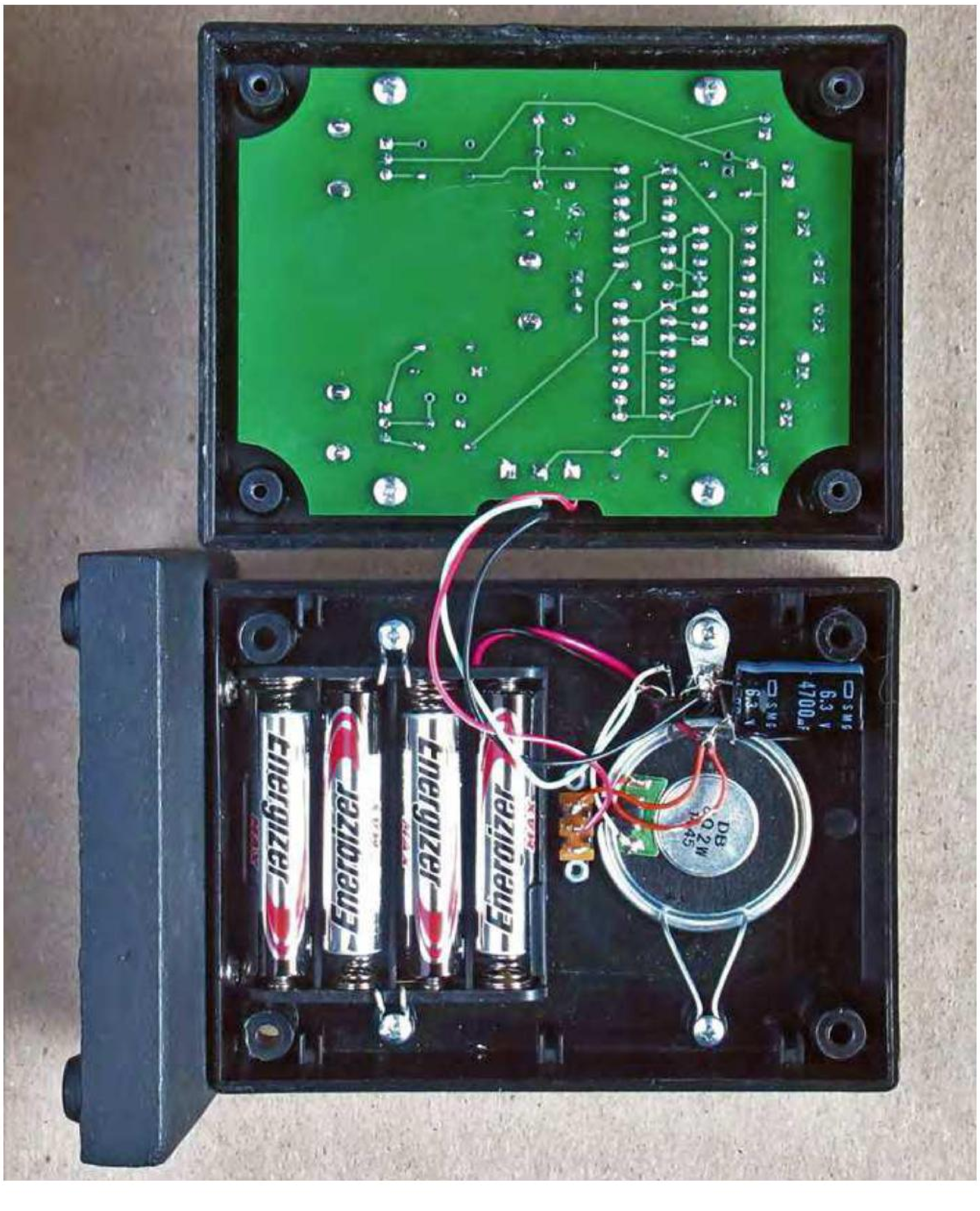


Fig.9: there are two dials for the 10-LED Metronome to suit the larger 300° potentiometer (left), or the standard 280° potentiometer (right). Unlike the 8-LED version, these are printed on transparent film and connected to the rotating pot shaft. Thus LED10 behind can shine through and illuminate the selected tempo.

Adjustments

The tempo and its range will likely need adjustment. Eight different 74HC132 ICs showed a spread of a few percent, with one about 7% above the average. The tempo may



For the LED Metronome, some of the components such as the speaker and battery holder are not mounted on the PCB, but are instead fitted onto the rear of the enclosure. This photo shows the 8-LED Metronome arrangement.

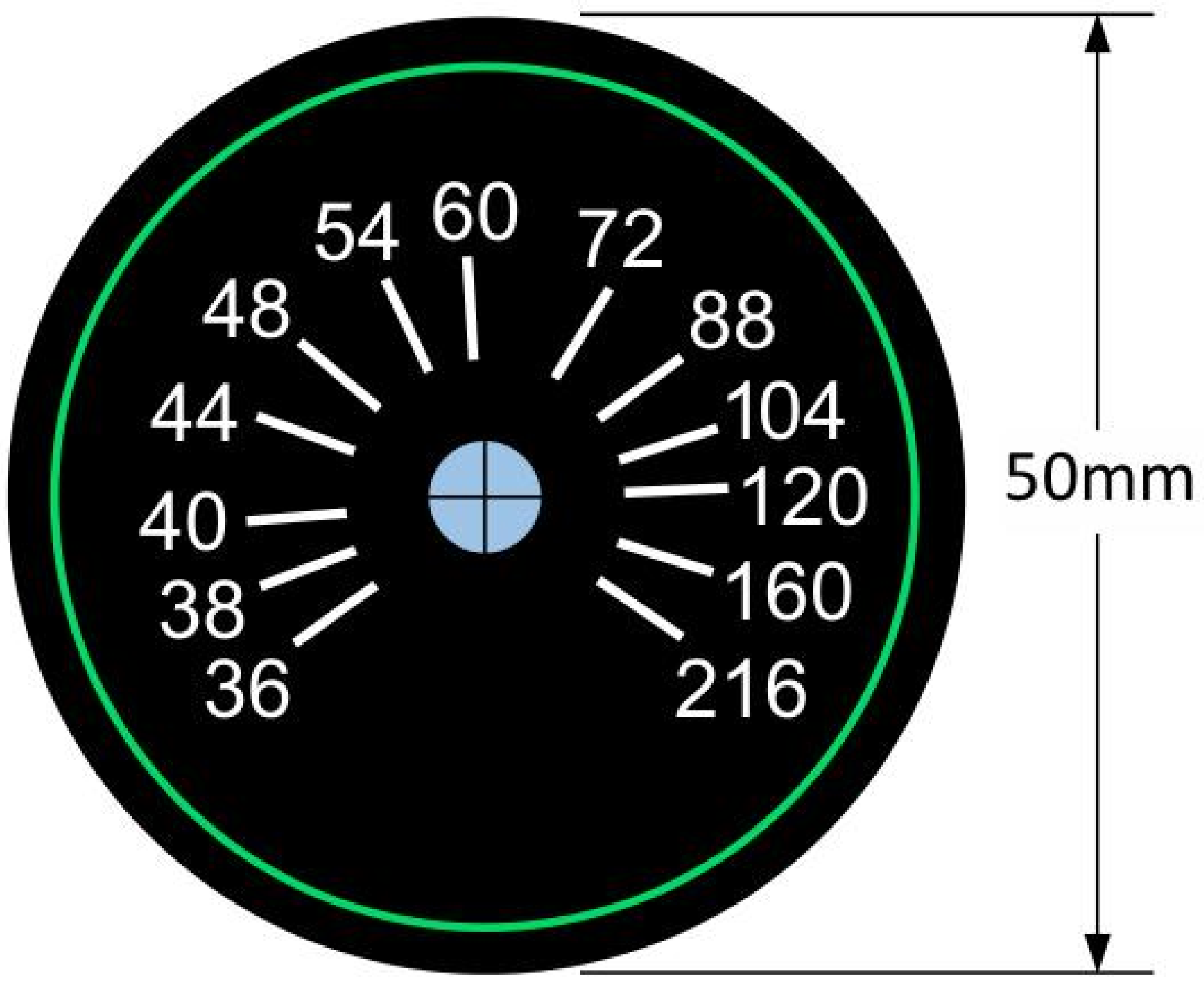


Fig.8: print this dial artwork for the 8-LED version on photo paper, cut it out and glue it to the front of the case. The exact diameter is not critical, but it should be close to 50mm. This is available to download as a PDF from the January 2023 page of the PE website (https://bit.ly/pe-downloads.

not correspond to the dial markings because of this, plus variations in the timing capacitors and the resistances of VR1 and R1/R2. Pots can vary by as much as 20%.

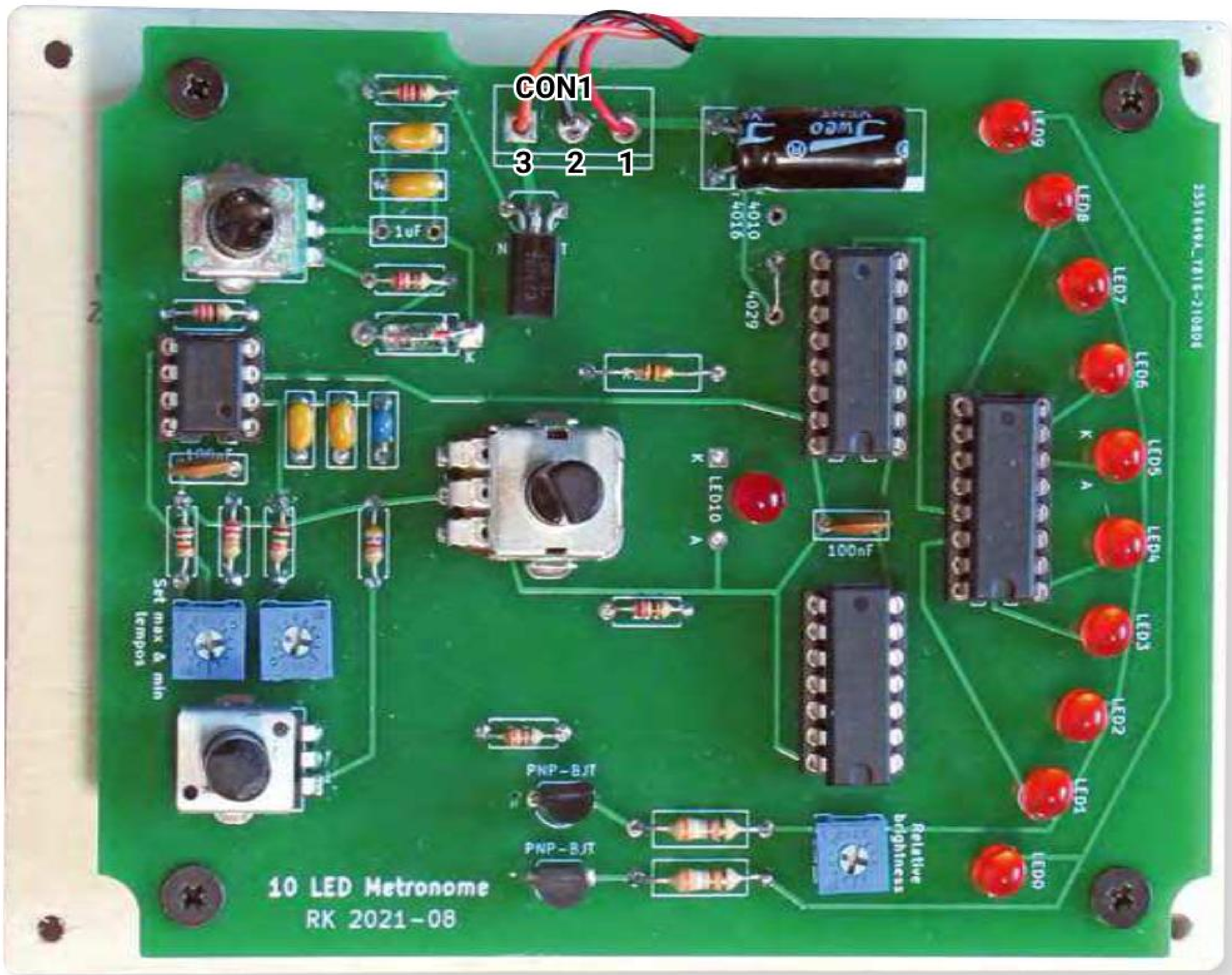
If you are not happy and want to bring the tempos into agreement, a frequency meter is very helpful. The type built into many low-cost DMMs is adequate.

Measure the pulse frequency at pin 11 of IC1 or pin 14 of IC2. With VR1 set at the lowest tempo (aligned with the marking showing 36 beats/minute), find a capacitor or paralleled capacitors for C1-C3 that give a pulse frequency of 4.2Hz (see Table 1).

If you don't have a selection of capacitors to try out (or want to save time), calculate the percentage error in the frequency (actual vs expected) and measure the capacitance across C1-C3. Multiply the capacitance reading by the percentage and divide by 100. This is how much capacitance you need to add (if it's too fast) or subtract (if it's too slow).

To subtract capacitance, you'll need to replace C1 and/or C2 with lower value capacitors, then re-check and possibly add a bit more capacitance by fitting C3 to get the frequency spot-on.

Assuming you selected R1 and R2 as 1/5th the value of VR1, with VR1 aligned with 216 beats/min, you should get a frequency reading of 25.2Hz (see Table 1). If this is significantly off, you might want to adjust those resistor values, reducing the total to speed it up or increasing them to slow it down. Calculating the percentage frequency error relative to 25.2Hz tells you the percentage by which the total resistance must change.



Similar to the 8-LED Metronome, the 10-LED metronome also has components mounted on the rear panel rather than on the PCB, as can be seen in the photo below, with the wires emanating from the top of this one.

The final result should have all tempos from 36 to 216 (and thus pulse frequencies in Table 1) agreeing with the dial markings.

Finally, check the click loudness and timbre. Check that VR3 varies the click loudness smoothly from zero to maximum. If it is too soft at maximum, a transistor with a higher h_{FE} is needed. If the click does not vary smoothly, replace the 220Ω resistor with a higher value until the loudness variation is satisfactory.

You can vary the timbre of the click by adding a capacitor at the position marked C5. Adding capacitance should give a more 'mellow' click. You can also try the speaker in both polarities as that can affect the sound.

Troubleshooting

If the LEDs don't light up or behave strangely, check the orientation of all the parts.

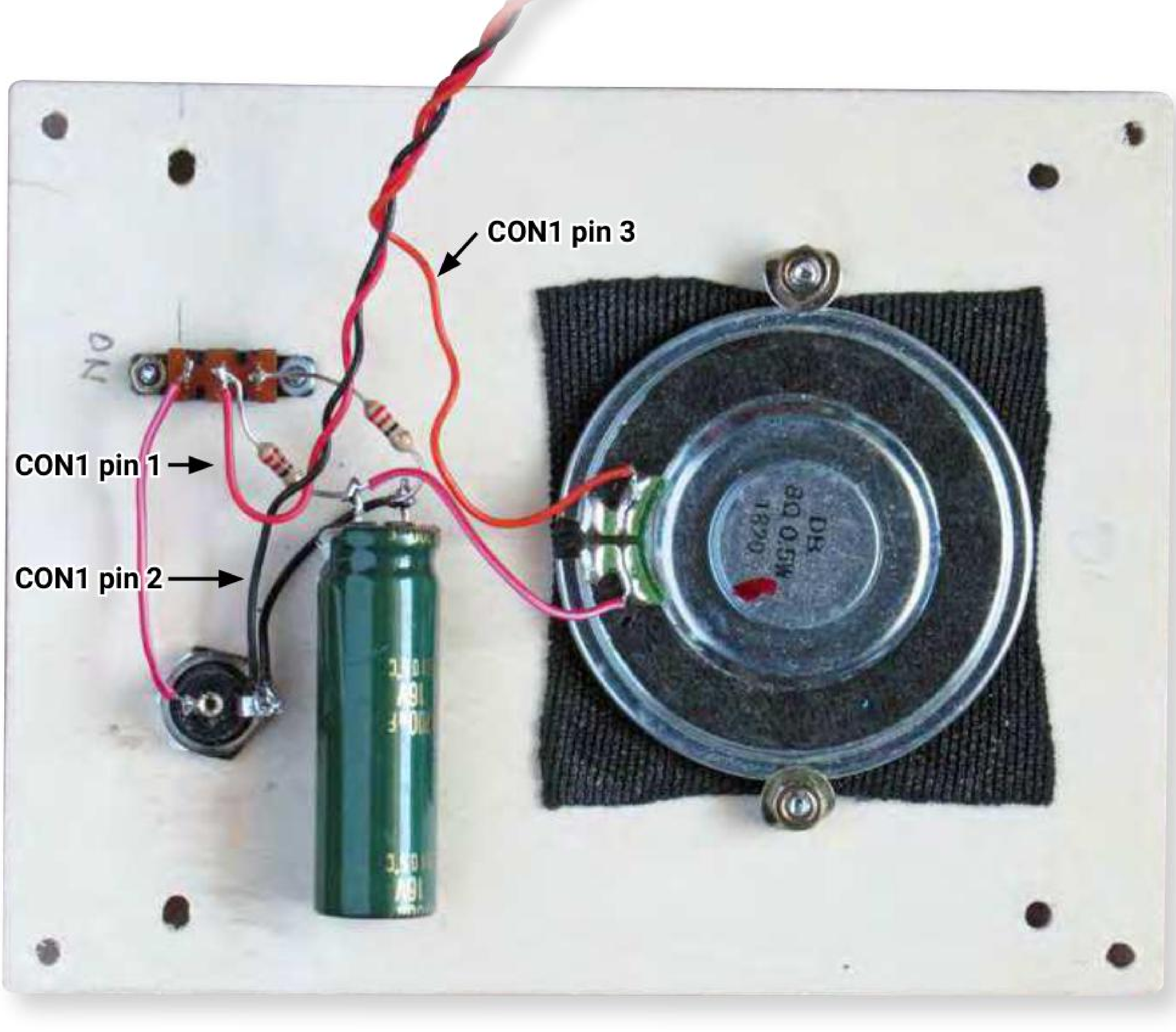
Check for solder bridges or poor joints and that IC pins are not bent. Check also that there is a pulse at pin 11 of IC1 and pin 14 of IC2.

Finishing the 10-LED Metronome

The mounting holes for VR2 can accept a 280° pot (matching the others) or a

Table 1 – Pulse frequency (Hz) versus tempo (beats/minute)

Tempo (bpm)	8 LEDs (Hz)	10 LEDs (Hz)
36	4.20	5.40
38	4.43	5.70
40	4.67	6.00
44	5.13	6.60
48	5.60	7.20
54	6.30	8.10
60	7.00	9.00
66	7.70	9.90
72	8.40	10.8
80	9.33	12.0
88	10.3	13.2
104	12.1	15.6
120	14.0	18.0
160	18.7	24.0
216	25.2	32.4



larger 300° pot. While the difference is subtle, the 300° pot allows the tempo numbers to be spread out slightly more. Before fitting VR2, measure its resistance, divide by 5.5 and check that this is close to 18kΩ. If not, you might need to replace the 18kΩ resistor with a different value that's close to this.

If your IC3 is a 4029, fit the solid red wire link shown in Fig.6. Otherwise, fit the wire link where there is a dashed red line. You can use a component lead off-cut for either.

Insert LED10 through the PCB from the back (see the photo on page 23). Solder its leads on the back of the PCB to pads 'K' and 'A'.

Rather than a dial applique, as used in the *8-LED* version, the *10-LED Metronome* uses a transparent plastic disc printed black with clear tempo numbers (Fig.9). Choose the design appropriate for your VR2 potentiometer type. If the printed disc is not sufficiently rigid, a clear backing disc might be needed.

Glue the disc to the back of a plastic bushing fitted by friction or glue onto the shaft of VR2. This bushing can be made from a cut-down knob. LED10 illuminates the tempo numbers of the disc to show through the plastic panel. LED10's brightness is determined by the value of resistor R2, specified as 10kΩ; if you aren't happy with the brightness, lower the value of R2 to make it brighter or increase it to make it dimmer.

For the *10-LED* version, the LEDs do not protrude through the front panel, but show through, so holes for the LEDs are not needed. The holes for the two lowest potentiometers (VR5/6) can be 8mm, but VR2 will require a larger hole to accommodate the bushing holding the tempo dial.

You will need to cut a thin panel on which to mount the PCB with 15mm threaded standoffs. This panel will fit into the back of the timber frame. This panel also carries the speaker, power jack, power switch, 4700µF electrolytic and two 22Ω resistors (see photo). Use the correct power socket to match your plugpack output.

The speaker is held in place by screws and nuts, with washers that have been bent down on one side. You can use hot melt glue or silicone sealant to secure the large electrolytic capacitor.

This panel, and thus the PCB, is secured to the frame by small wood screws that attach to four approximately 8 x 8 x 12mm pieces of timber glued to the inside corners of the frame.

There's nothing extraordinary about the case; I made mine in the same manner as a picture frame, with four 45° mitred timber pieces glued together. If you don't like doing woodwork, you could probably find a plastic box with a clear lid that's large enough to house the PCB and other components, and drill holes in the lid for the pots.

Parts List – 8-/10-LED Metronome

8-LED Metronome

1 double-sided PCB coded 23111211, 71 x 98mm (from the *PE PCB Service*)
1 3-way terminal block (CON1)
1 Serpac 131-BK plastic instrument case, 111 x 82.5 x 38mm **[Mouser 635-131-B, Digi-Key SR131B-ND]**
1 timber base, 75 x 90 x 12.5mm (DIY)
4 AAA cells, preferably NiMH rechargeables (BAT1)
1 4xAAA battery holder (BAT1) **[Keystone Electronics 2482; Mouser 534-2482, Digi-Key 36-2482-ND]**
1 8Ω loudspeaker, 36mm diameter (SPK1) **[DB Unlimited SM360608-1; Mouser 497-SM360608-1, Digi-Key 2104-SM260608-1-ND]**
1 100kΩ linear 9mm/10mm vertical potentiometer (VR1) **[Mouser 652-PTV09A4025UB104]**
1 500kΩ linear 9mm/10mm vertical potentiometer (VR2) **[Mouser 652-PTV09A4020UB504]**
1 5kΩ linear 9mm/10mm vertical potentiometer (VR3) **[Mouser 652-PTV09A4030UB502, Digi-Key PTV09A4030UB502-ND]**
1 SPST or SPDT slide switch (S1) **[Alpha SS60012F-0102-4V-NB; Mouser SS60012F-0102-4V-NB]**
1 14-pin DIL IC socket (**optional**; for IC1)
2 16-pin DIL IC sockets (**optional**; for IC2 and IC3)
3 knobs to suit VR1-VR3
4 adhesive rubber feet
2 small machine screws and nuts (for mounting slide switch)
1 large, heavy-duty paper clip
8 No.4 x 6mm self-tapping screws
2 small, short (~10mm) panhead wood screws (for mounting case to base)
1 solder lug with ~3.25mm diameter hole
various lengths and colours of light-duty hookup wire

Semiconductors
1 74HC132 quad 2-input Schmitt-trigger NAND gate, DIP-14 (IC1)
1 74HC191 presettable 4-bit binary up/down counter, DIP-16 (IC2)
1 74HC137 or 74HC138 3-to-8 line decoder, DIP-16 (IC3)
1 30V 1A NPN transistor, TO-92 (Q1) **[KSD471ACYTA, KSC2328AYTA or ZTX690B]**
8 'superbright' LEDs, round or oval (LED0-LED7) **[Broadcom HLMP-HM74-34CDD (green, oval), Kingbright WP7083ZGD/G (green, 5mm), Jameco 2169846 (green, 3mm)]**
1 6.0V 500mW zener diode (ZD1) **[1N5233 or equivalent]**
1 blue/white LED or 4.7V zener diode (LED8/ZD2) **[1N5231]**
1 150mA schottky diode; eg, BAT46/BAT48/BAT85 (D1) **[Jaycar ZR1141, Altronics Z0044, Mouser 511-BAT46]**

Capacitors
1 4700µF 6.3V electrolytic **[Mouser 667-EEU-FS0J472]**
1 470µF 6.3V low-profile electrolytic **[Mouser 232-63AX470MEFC8X75]**
4 1µF 50V multi-layer ceramic
1 100nF 50V ceramic
1 220pF 50V ceramic

Resistors *(1% $\frac{1}{4}$W, $\frac{1}{8}$W or $\frac{1}{16}$W small body metal film unless otherwise stated)*
1 300kΩ (**optional**)
2 10kΩ
1 2.2kΩ
2 220Ω
1 47Ω

While we recommend using 1% resistors, you can use 5% resistors if desired. It might need more adjustments to get the tempo range correct.

10-LED Metronome

1 double-sided PCB coded 23111212, 108 x 89mm (from the *PE PCB Service*)
1 12V DC 100mA+ plugpack

Checkout and adjustment

Before applying power, carefully check the wiring to the off-board components; a mistake here can cause excessive current and damage Q3 or cook the speaker

1 3-way terminal block (CON1)
1 chassis-mount barrel socket to suit plugpack (CON2)
1 8Ω loudspeaker, 50mm diameter (SPK1)
  [DB Unlimited SM500208-1; Mouser 497-SM500208-1]
2 5kΩ top-adjust mini trimpots (VR1, VR3)
1 100kΩ 280° linear 9mm/10mm vertical potentiometer (VR2)
  [Mouser 652-PTV09A4025UB104] ***OR***
1 100kΩ 300° linear 9mm/10mm vertical potentiometer (VR2)
  [Mouser 652-PDB12-M4251-104BF] (see text)
1 100kΩ top-adjust mini trimpot (VR4)
1 20kΩ linear 9mm/10mm vertical potentiometer (VR5)
  [Mouser 652-PTV09A-4030UB203, Digi-Key PTV09A-4030U-B203-ND]
1 5kΩ linear 9mm/10mm vertical potentiometer (VR6)
  [Mouser 652-PTV09A4030UB502, Digi-Key PTV09A4030UB502-ND]
1 SPDT slide switch (S1) **[Alpha SS60012F-0102-4V-NB;**
  Mouser SS60012F-0102-4V-NB]
1 14-pin low-profile DIL IC socket (**optional**; for IC1)
1 8-pin low-profile DIL IC socket (**optional**; for IC2)
2 16-pin low-profile DIL IC sockets (**optional**; for IC3 and IC4)
1 timber base, 75 x 150 x 12mm (DIY)
1 timber frame, 110 x 130 x 40mm (DIY)
1 red-tinted transparent acrylic panel, 100 x 125 x 2.5-3mm (or to fit frame)
3 knobs to suit VR2, VR5 and VR6
1 clear, printable plastic and plastic backing for tempo dial, bushing or cut-down knob for mounting onto VR2
4 M3-tapped 15mm spacers (for mounting PCB to panel)
8 M3 x 6mm panhead machine screws (for mounting PCB to panel)
2 small machine screws and nuts (for mounting slide switch)
2 M3 x 10mm panhead machine screws, flat washers and nuts (for mounting speaker)
1 large, heavy-duty paper clip
6 small, short (~10mm) panhead wood screws
various lengths and colours of light-duty hookup wire
1 55x55mm square of speaker cloth

Semiconductors

1 CD4001BE quad 2-input NOR gate, DIP-14 (IC1)
1 TLC555IP or LMC555CN CMOS timer, DIP-8 (IC2)
1 CD4029BE, CD4510BE or CD4516BE 4-bit binary up/down counter, DIP-16 (IC3)
1 CD4028BE 4-to-10 binary decoder, DIP-16 (IC4)
2 BC558 30V 100mA PNP transistors, TO-92 (Q1, Q2)
1 30V 2A NPN transistor, TO-92 (Q3) **[KSC2328AYTA or ZTX690B]**
1 150mA schottky diode; eg, BAT46/BAT48/BAT85 (D1)
  [Jaycar ZR1141, Altronics Z0044, Mouser 511-BAT46]
10 'superbright' LEDs, round or oval (LED0-LED9)
  [Cree C566D-RFE-CV0X0BB1 (red, oval) recommended]
1 5mm 'superbright' red LED (LED10) **[Kingbright WP7113SRD/J4 recommended]**

Capacitors

1 4700µF 16V electrolytic, 13mm diameter **[Mouser 232-16PK4700MEFC125X]**
1 1000µF 16V electrolytic, 8mm diameter **[Mouser 232-16ZLH1000MEFC8X2]**
5 1µF 50V multi-layer ceramic
2 100nF 50V ceramic

Resistors *(1% ¼W, ⅛W or 1⁄16W small body metal film unless otherwise stated)*

1 22kΩ
1 3.3kΩ
1 18kΩ
2 390Ω ½W
2 10kΩ
4 220Ω
1 4.7kΩ
2 22Ω

coil or cone. Compare your wiring to that shown in our photos.

Because of variations in components, the tempo will likely need to be brought into line. A frequency meter (even a very basic one as found in many DMMs) or scope is helpful for adjusting the tempos.

Turn VR2 to the slowest tempo (36 beats/min) and measure the pulse frequency at pin 3 of IC2 or pin 15 of IC3. Adjust the control voltage (pin 5) of the timer (IC2) via trimpot VR1 to get a frequency of 5.4Hz (see Table 1). If adjusting trimpot VR1 cannot bring the frequency to 5.4Hz, you need to add another capacitor in parallel with C1 and C2 (at position C3) to slow it down, or reduce the value of C1 and/or C2 to speed it up.

Once this frequency is correct, set the tempo to 216 beats/min and adjust trimpot VR3 to get 32.4Hz. If VR3 cannot bring the frequency to 32.4Hz, change the value of its 18kΩ series resistor, then repeat the adjustments for the slowest and fastest tempos.

Finally, adjust trimpot VR4 to the desired difference in brightness between the two end LEDs and the middle LEDs.

Click timbre and loudness can also be modified for the *10-LED* version. Adjust the value of resistor R1 for a smooth variation in loudness, as described for the *8-LED* version.

To change the timbre of the click, you need to experiment with the combined value of C4-C6. A larger capacitance should produce a more mellow click. The speaker can also affect the tone, so try the speaker in both polarities if you aren't satisfied with the initial result.

Troubleshooting

If the *Metronome* is not working, check the orientation of IC2 and associated parts. Also, check that the IC pins are all inserted correctly; they sometimes get bent and don't go into the socket or PCB. Check if there is a pulse at pin 3 of IC2 and pin 15 of IC3.

If the LED sequence is only in one direction, it is likely that the SR-FF is not working or not receiving the S and R pulses from IC4.

Operation

The operation of either version is straightforward. Turn the *Metronome* on and adjust the Click Loudness, LED Brightness and Tempo as desired.

The supply current for the 8-LED Metronome is about 2-4mA, depending on the LED brightness, click loudness and tempo. AAA cells typically are rated at about 900mAh. Thus, assuming it is used for about half an hour a day, alkaline or rechargeable cells should power the *8-LED* version for about a month.

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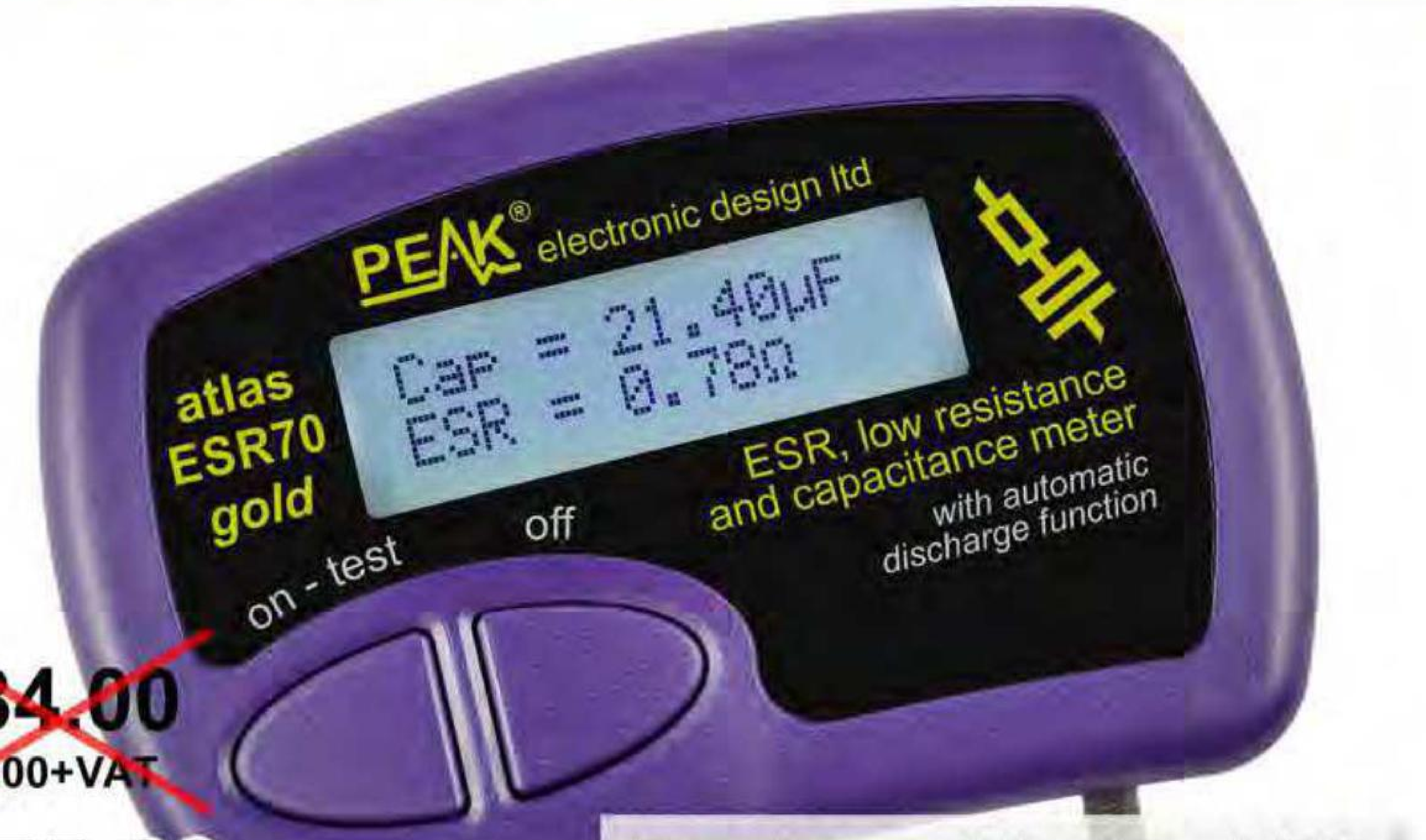
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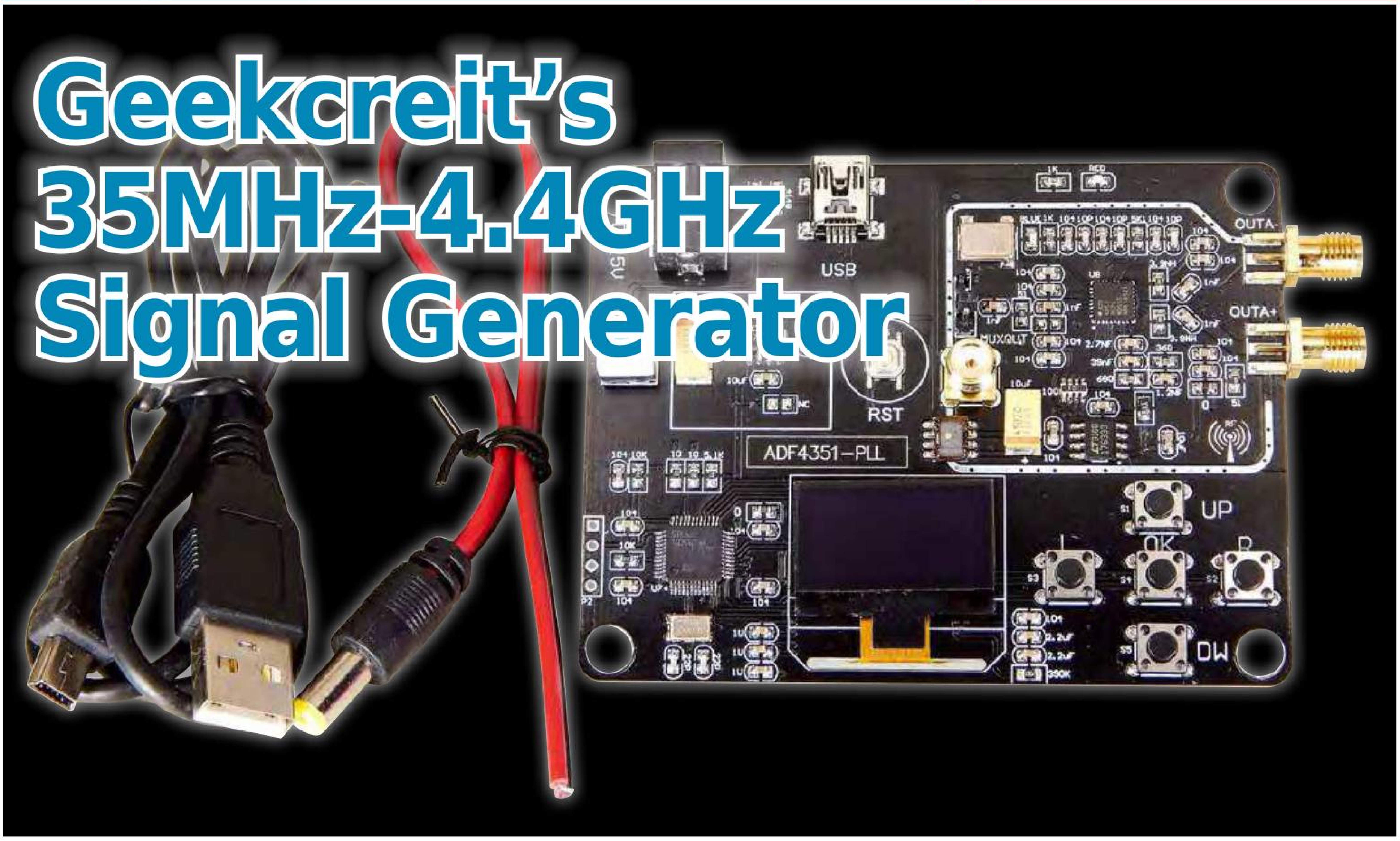


This self-contained module is based on the Analog Devices ADF4351 wideband digital synthesiser chip. It has an onboard microcontroller unit (MCU), OLED display and pushbuttons to set the desired frequency and adjust the output level. All it needs is a 5V DC power supply.

If the ADF4351 sounds familiar, that's because it was also used in the digitally-controlled oscillator we reviewed (May 2019). But whereas the earlier unit needed to be controlled via a separate microcontroller such as an Arduino or a Micromite, this one is a self-contained instrument, delivered ready to use.

It is larger than the earlier one, measuring 88 x 67mm compared to 48 x 36.5mm. But the price isn't all that much higher, currently setting you back £30 including shipping to the UK. It can be purchased from Banggood (**https://bit.ly/pe-dec22-bg**).

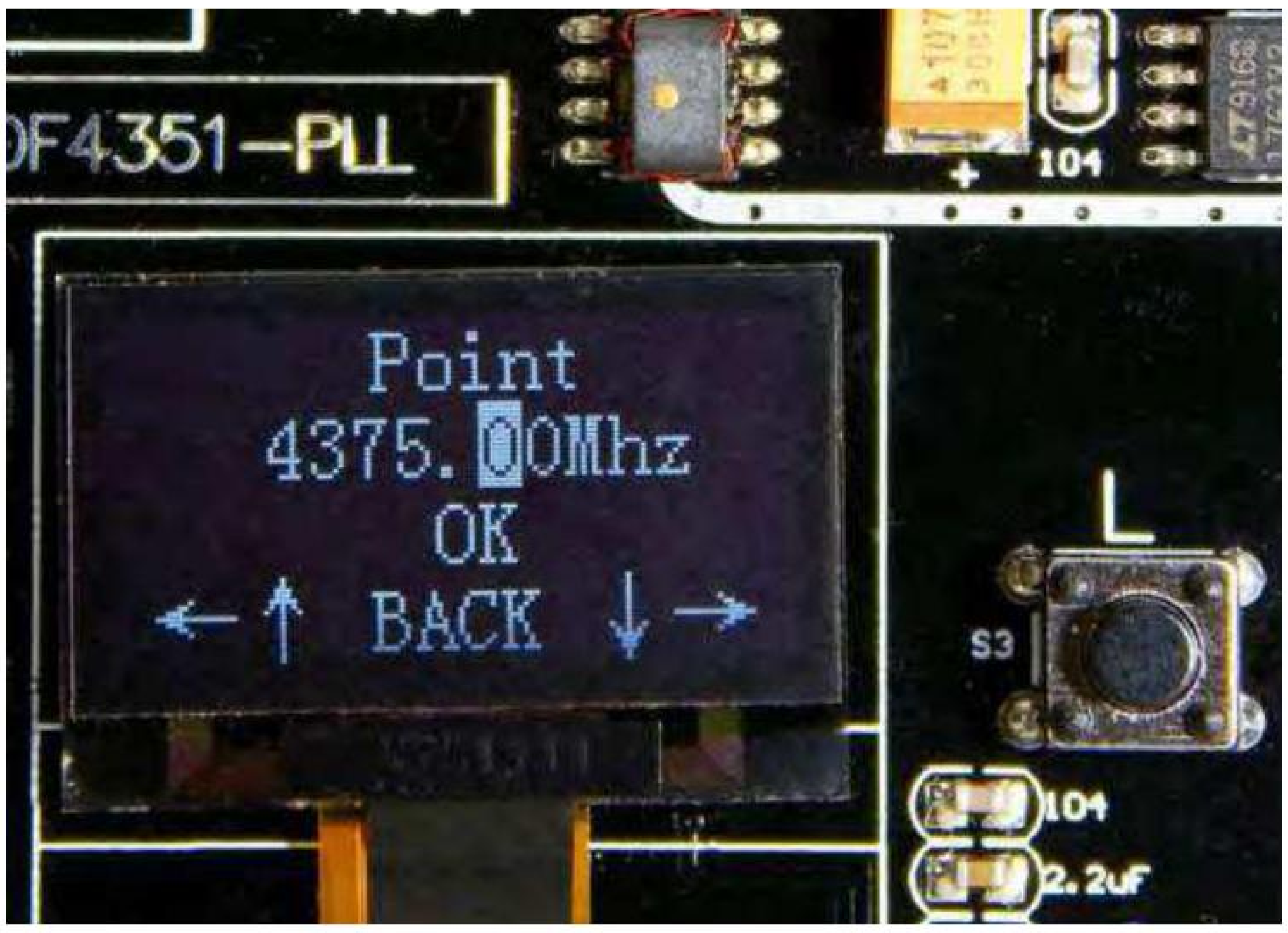
As shown in the photos, it comes with two cables: a USB Type-A to mini-B cable and a 240mm-long DC cable with a plug on one end to match the module's DC input socket.

It also comes fitted with four 5mm-long nylon mounting spacers and matching screws. But no case is supplied, so you'll either need to use it as a 'bare' module, or come up with your own arrangement.

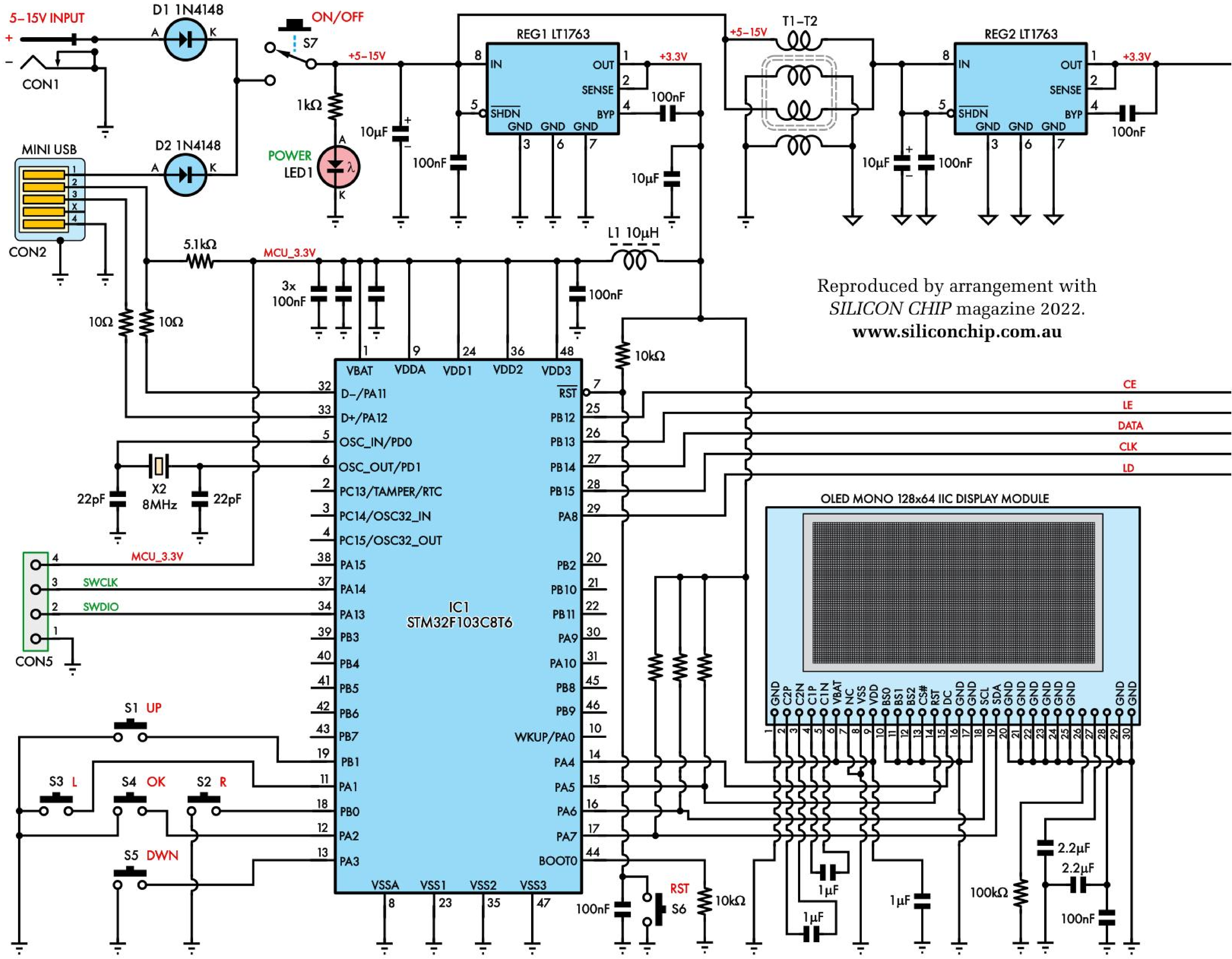
On the PCB, there's an STM32F103 MCU (lower left), a small OLED (organic light-emitting diode) display with a 128 x 64 pixel 25mm (1-inch) diagonal screen, and seven pushbutton switches. The five at lower right control the module, while the one in the centre resets the MCU. The one near the upper left with a square body and blue actuator is the ON/OFF switch.

The ADF4351 synthesiser chip and its surrounding components are all in the upper right-hand corner of the PCB. The two nearby edge-mounted SMA sockets are the RF outputs, while the vertical SMA socket near the centre of the PCB is an input for an optional external master clock, an alternative to the onboard 100MHz crystal oscillator.

The ADF4351 chip at the heart of the module is a digital 'phase-locked loop' or PLL device, and a pretty fancy one at that. But there isn't space here to give you a full explanation of PLLs and how the ADF4351 itself works. So if you want to know more about these aspects, refer to the May 2019 article: *35MHz-4.4GHz digitally controlled oscillator*, which has a comprehensive explanation.



A close-up of the 1-inch OLED screen when using the 'Point' command from the main screen.


5–15V INPUT
CON1
D1 1N4148
D2 1N4148
MINI USB
CON2
ON/OFF
S7
+5–15V
1kΩ
POWER
LED1
10µF
100nF
REG1 LT1763
IN
OUT
SENSE
SHDN
BYP
GND GND GND
+3.3V
100nF
10µF
T1–T2
REG2 LT1763
+3.3V
100nF
5.1kΩ
MCU_3.3V
3x 100nF
L1 10µH
100nF
10Ω
10Ω
10kΩ
VBAT VDDA VDD1 VDD2 VDD3
D–/PA11
D+/PA12
OSC_IN/PD0
OSC_OUT/PD1
PC13/TAMPER/RTC
PC14/OSC32_IN
PC15/OSC32_OUT
PA15
PA14
PA13
PB3
PB4
PB5
PB6
PB7
PB1
PA1
PB0
PA2
PA3
RST
PB12
PB13
PB14
PB15
PA8
PB2
PB10
PB11
PA9
PA10
PB8
PB9
WKUP/PA0
PA4
PA5
PA6
PA7
BOOT0
VSSA VSS1 VSS2 VSS3
IC1
STM32F103C8T6
X2
8MHz
22pF
22pF
MCU_3.3V
SWCLK
SWDIO
CON5
S1 UP
S3 L
S4 OK
S2 R
S5 DWN
CE
LE
DATA
CLK
LD
OLED MONO 128x64 IIC DISPLAY MODULE
GND C2P C2N C1P C1N VBAT NC VSS VDD BS0 BS1 BS2 CS# RST DC GND GND SCL SDA GND GND GND GND GND GND GND GND GND GND GND
RST
S6
100nF
10kΩ
1µF
1µF
1µF
100kΩ
2.2µF
2.2µF
100nF

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Geekcreit 35MHz – 4.4GHz Signal Generator Module

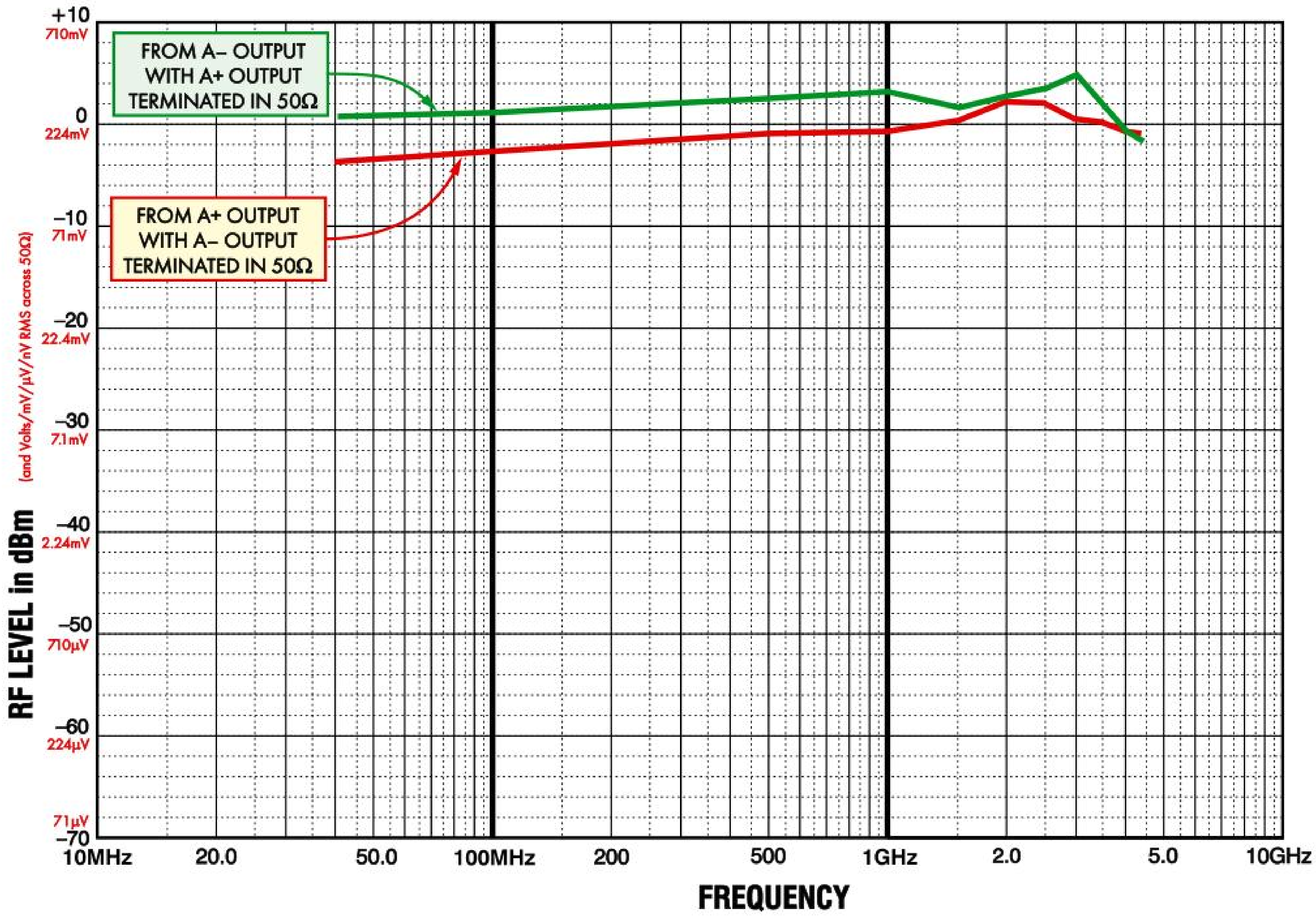


Fig.2: plot of the output level vs frequency when terminated by 50Ω.

A brief rundown

The ADF4351 is a wideband digital synthesiser IC with a 'fractional-N' PLL, allowing it to be programmed to produce any desired output frequency between 35MHz and 4.4GHz. It is locked to a 'master clock' crystal oscillator of typically 25MHz or 100MHz.

It can be programmed to change the output frequency in steps as small as 10kHz, and can also provide an output sweeping over a range of frequencies in steps of the same minimum size.

The whole chip is controlled/programmed via a simple three-wire serial peripheral interface (SPI), in this case, via the onboard STM32F103 MCU.

The data sheet for the ADF4351 can be found at: **https://bit.ly/pe-dec22-ad1**

Lack of instructions

The Geekcreit 35-4400MHz signal generator module comes with very little user information, so you have to work a lot out for yourself. All you get is a brief summary of its main specs and features,

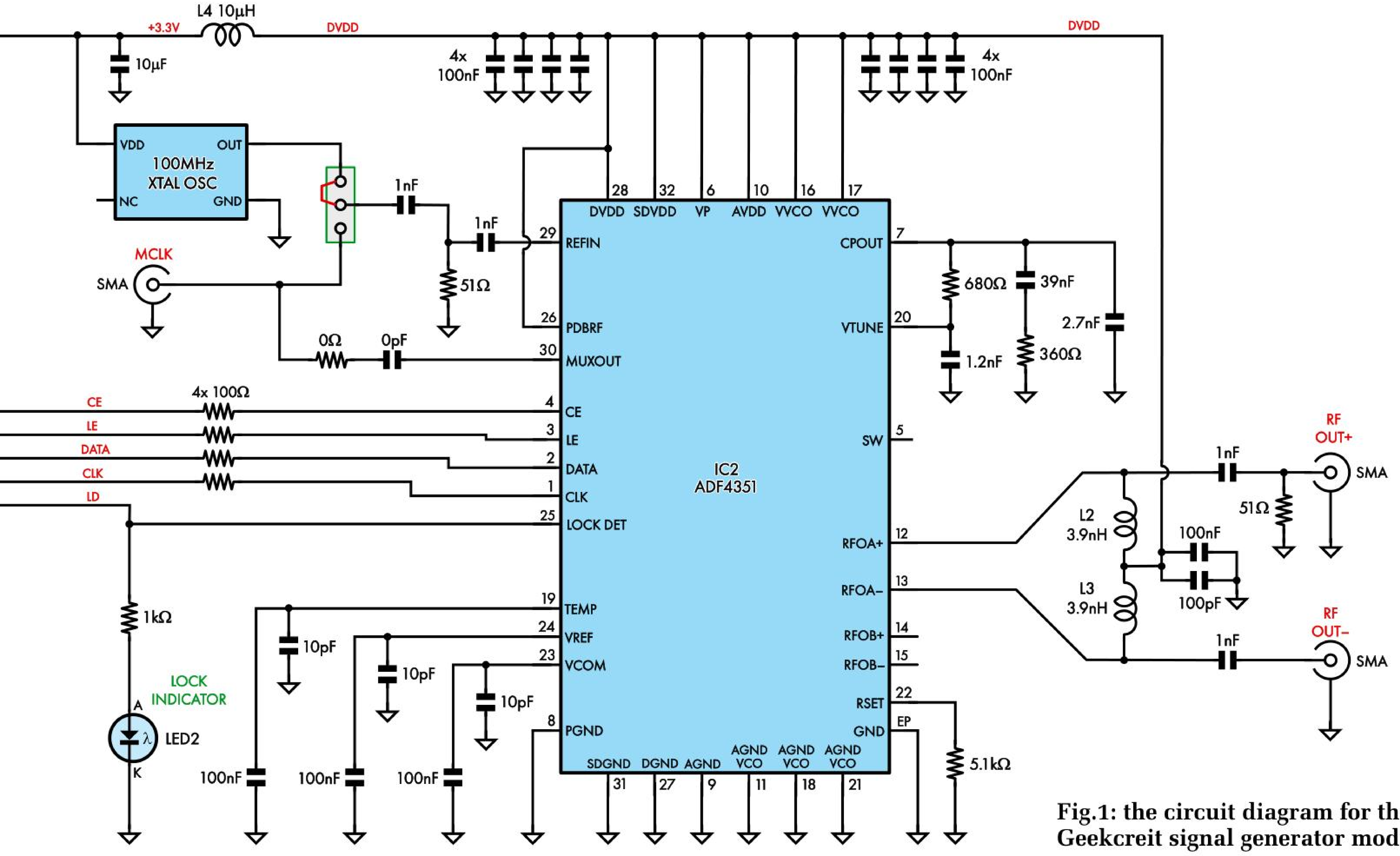

+3.3V
L4 10µH
DVDD
10µF
4x 100nF
4x 100nF
DVDD
VDD
OUT
100MHz XTAL OSC
NC
GND
1nF
1nF
51Ω
MCLK
SMA
0Ω
0pF
4x 100Ω
CE
LE
DATA
CLK
LD
28 DVDD
32 SDVDD
6 VP
10 AVDD
16 VVCO
17 VVCO
29 REFIN
26 PDBRF
30 MUXOUT
4 CE
3 LE
2 DATA
1 CLK
25 LOCK DET
19 TEMP
24 VREF
23 VCOM
8 PGND
IC2 ADF4351
7 CPOUT
20 VTUNE
5 SW
12 RFOA+
13 RFOA–
14 RFOB+
15 RFOB–
22 RSET
EP GND
SDGND 31
DGND 27
AGND 9
AGND VCO 11
AGND VCO 18
AGND VCO 21
680Ω
39nF
2.7nF
1.2nF
360Ω
5.1kΩ
1kΩ
LOCK INDICATOR
A
K
LED2
10pF
10pF
10pF
100nF
100nF
100nF
L2 3.9nH
L3 3.9nH
100nF
100pF
1nF
1nF
51Ω
RF OUT+
SMA
RF OUT–
SMA

Fig.1: the circuit diagram for the Geekcreit signal generator module.

and you can download a circuit diagram that is not easy to decipher.

So before I began testing the module, I spent a couple of hours redrawing the circuit so that we can all see how it works – see Fig.1.

Like the earlier module, this one is fairly closely based on Analog Devices' evaluation board for the ADF4351. That is described in their *User Guide UG-435*, which you can download from their website: **https://bit.ly/pe-dec22-ad2**

How it works

In Fig.1, the ADF4351 (IC2) is on the right, with its onboard 100MHz master clock oscillator to its left. These form the actual VHF-UHF RF synthesiser 'heart' of the module. The two complementary RF outputs emerge from pins 12 and 13 of IC2, and are fed via 1nF capacitors to the two SMA output sockets at far right. The 3.3V DC supply to pins 12 and 13 flows via inductors L2 and L3.

Only the RF output from pin 12 of IC2 (RF$_{OUT+}$) has an onboard 51Ω terminating resistor.

The other components on the right-hand side of Fig.1 are to provide IC2 with power, set its operating mode, or feed it control signals. For example, the components between pins 7 and 20 at upper right form the ADF4351's low-pass loop feedback filter (to optimise its performance), while the capacitors at pins 19, 23 and 24 bypass key reference points in its internal circuitry.

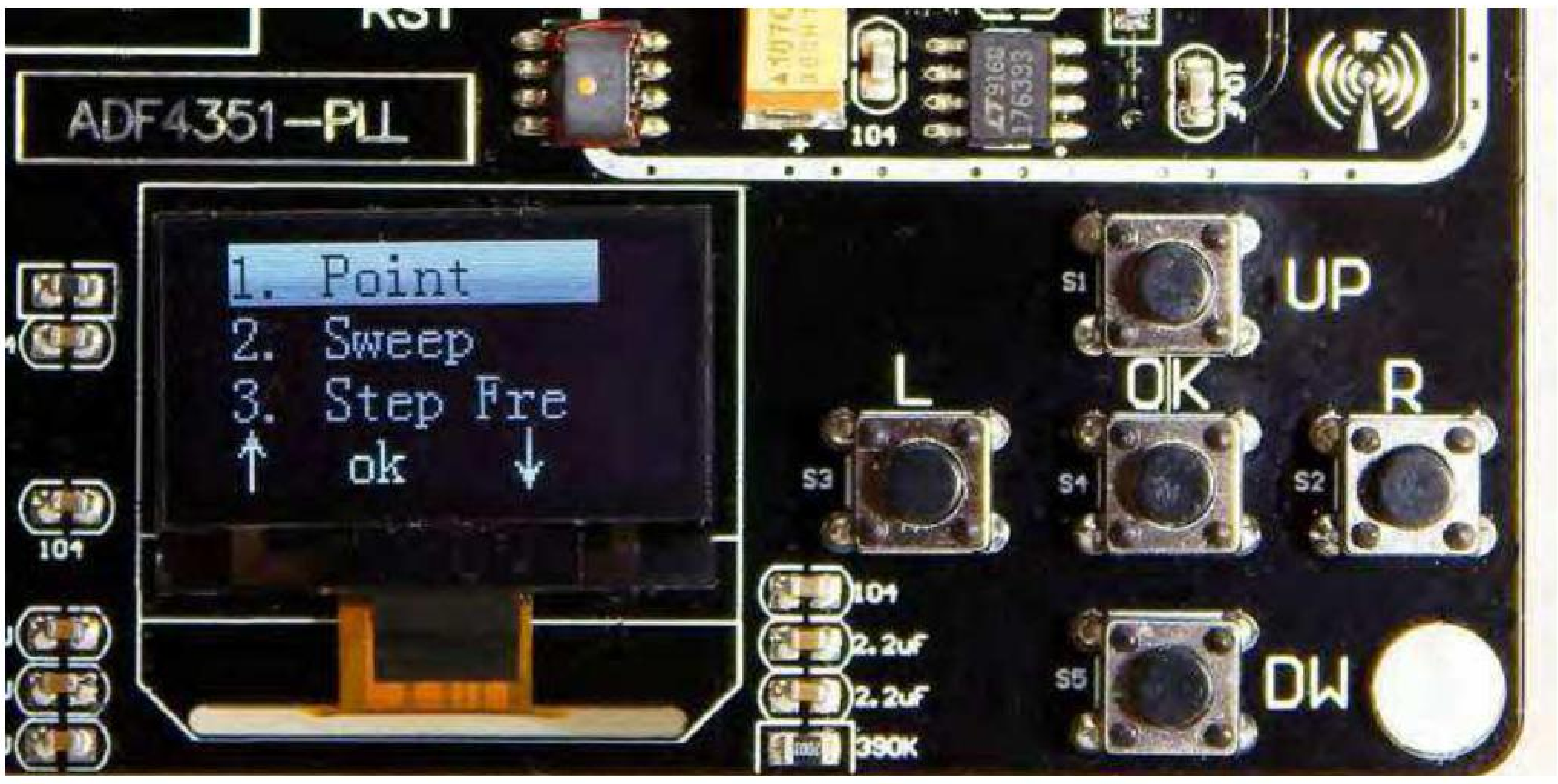
The digital control signals from IC1 that direct IC2's operation are fed to pins 1, 2, 3 and 4 at centre left, labelled CLK, DATA, LE and CE. The only other signal that passes back from IC2 is the LD (lock detect) signal from pin 25, which is high when IC2 is locked to the requested frequency.

As well as being fed back to the MCU, this signal is also used to illuminate LED2, the blue lock indicator.

The power supply section is at upper left in Fig.1. This accepts either 5V DC from mini USB socket CON2, or 5-15V DC from concentric DC socket CON1. This flows via on-off switch S7 to power indicator LED1 and the rest of the circuit. The incoming supply powers REG1 and REG2, both of which are LT1763 LDO (low drop-out) 3.3V linear regulators.

REG1 provides 3.3V to the control circuitry, while REG2 generates a separate 3.3V supply for synthesiser IC2. The incoming supply to REG2 is via T1-T2, a balanced decoupling transformer wound on a small ferrite balun core.

As mentioned earlier, the control circuitry is based around IC1, an STM32F103C8T6 microcontroller, and the 128 x 64-pixel OLED display


ADF4351–PLL
1. Point
2. Sweep
3. Step Fre
↑ ok ↓
S1
UP
L
OK
R
S3
S4
S2
S5
DW
104
2.2uF
2.2uF
390K

On starting the module, the OLED display lists the five available functions.

module to its right. The four digital signals to control synthesiser IC2 connect to pins 25-28 of IC1, while the LD signal from IC2 is fed back to pin 29.

Pushbuttons S1-S5 at lower left select the operating mode of the synthesiser, its operating frequency, output level and so on. The MCU provides a series of menus and indications on the OLED display to make this reasonably straightforward. The OLED display is driven via an SPI serial control link from pins 14-17 of IC1.

The instruction and master clock for IC1 is generated by an internal oscillator using 8MHz crystal X2, connected to pins 5 and 6.

Pushbutton S6 manually resets IC1 if necessary. The D– and D+ data lines from mini USB socket CON2 are connected to pins 32 and 33 of IC1, so its firmware can be updated from a PC if needed.

It's also possible to communicate with IC1 via a second serial link connected to pins 34 and 37, brought out to the pins of CON5. This is not a physical connector, but provision on the module's PCB for fitting a four-pin SIL header.

Trying it out

When I received the unit and tried powering it up, there were a couple of problems. The first of these was that the DC supply cable provided with it turned out to have an open circuit in its red (positive) lead. So I had to discard it and substitute a known good cable.

Then when I powered it up, I found that the module was on regardless of whether power switch S7 was pressed or not. The cause turned out to be a solder bridge under the PCB joining its two active pins permanently. Luckily, I fixed that easily with a soldering iron.

I also tried powering the unit from a 5V USB plug pack, using the USB Type A-to-mini Type B cable provided, which worked fine.

When the module is first powered up, the OLED screen shows its function menu, or more accurately, the top of it – listing the first three functions:

1. **Point:** used to set the module's frequency to a particular figure, for example 4375.05MHz
2. **Sweep:** used to set the start and stop frequencies for sweeping over a range
3. **Step Fre:** not clearly explained, but seems to be used to set the frequency steps used during sweeping

Then if you continue pressing the down (DWN) button, S5, you find the remaining two options:

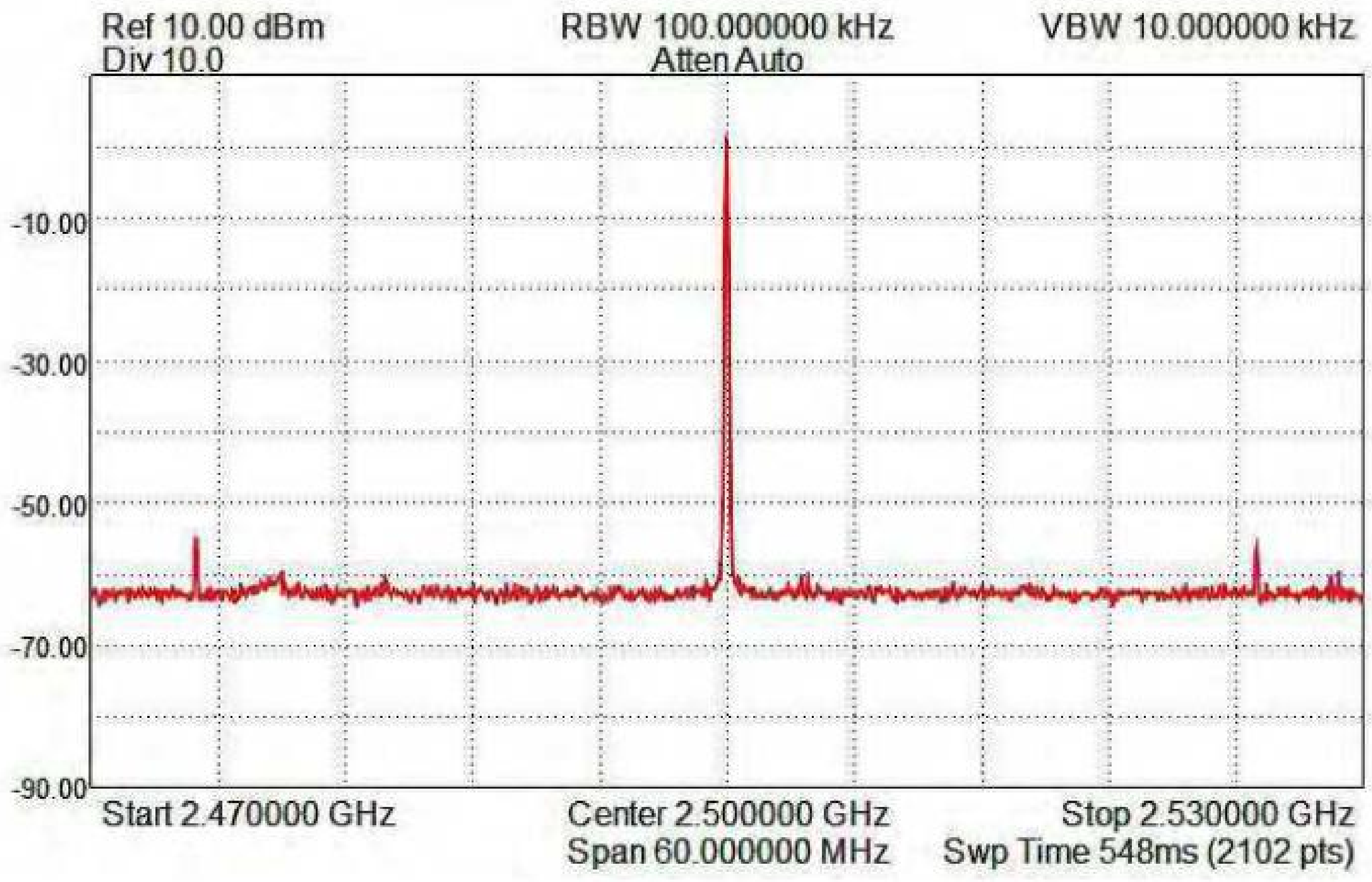


Fig.3: a graph of the module's output at 2.5GHz with a 60MHz span provides a reasonably clean plot with just two small spurs at the edges.

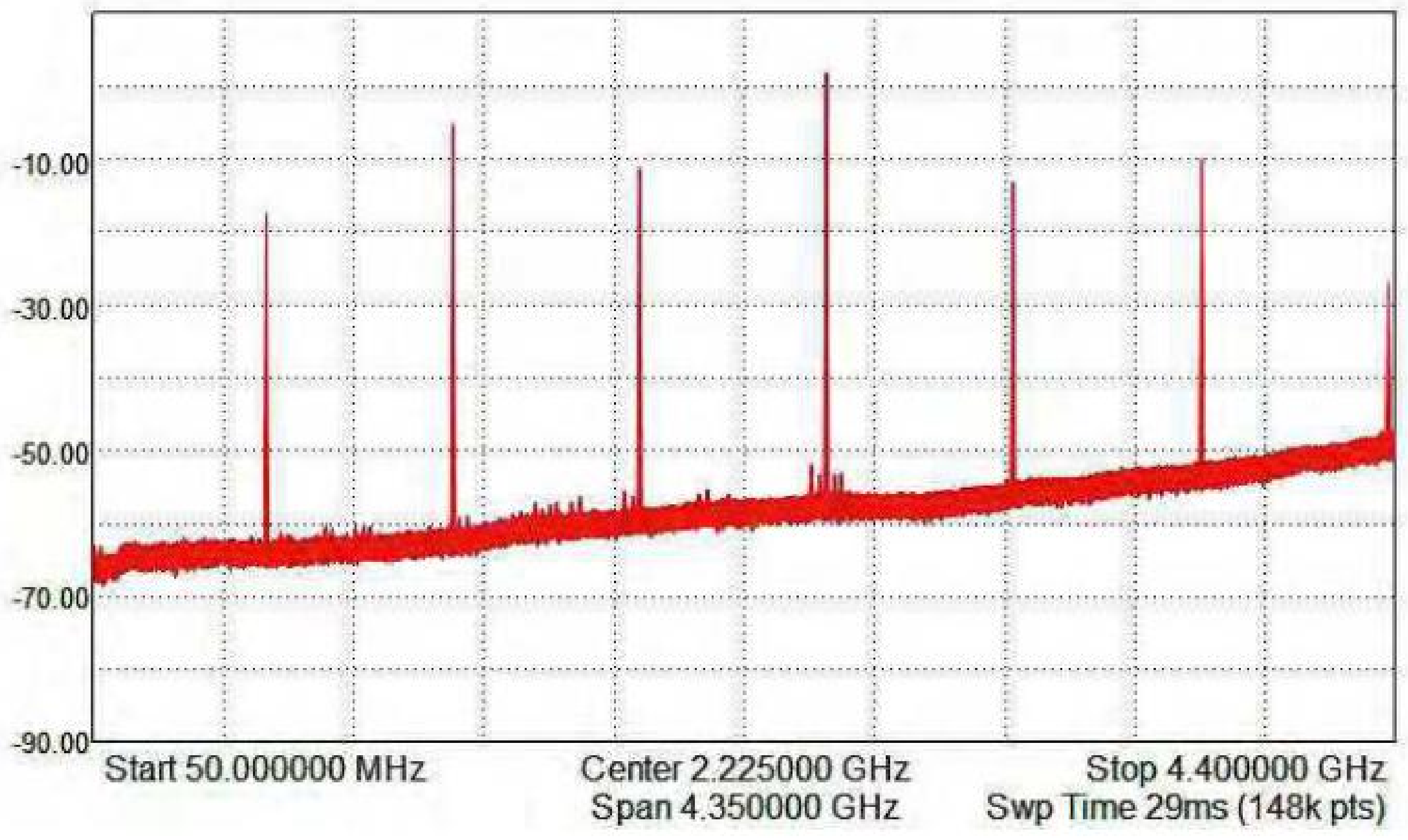


Fig.4: the span is now set over the range 50MHz to 4.4GHz with the same 2.5GHz output. Note the additional spurs approximately 600MHz apart.

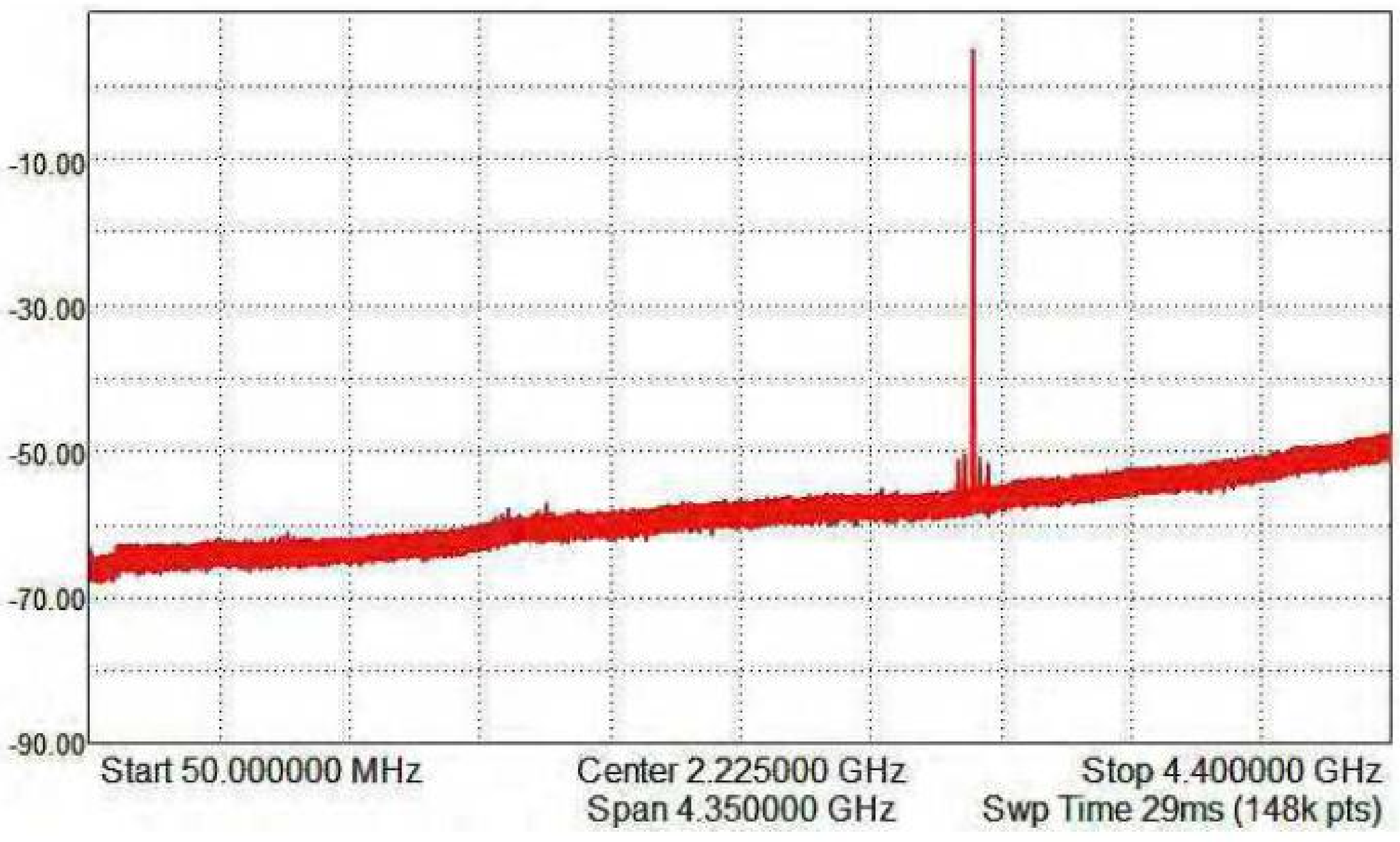


Fig.5: setting the output frequency higher to 3GHz also provides a clean plot.

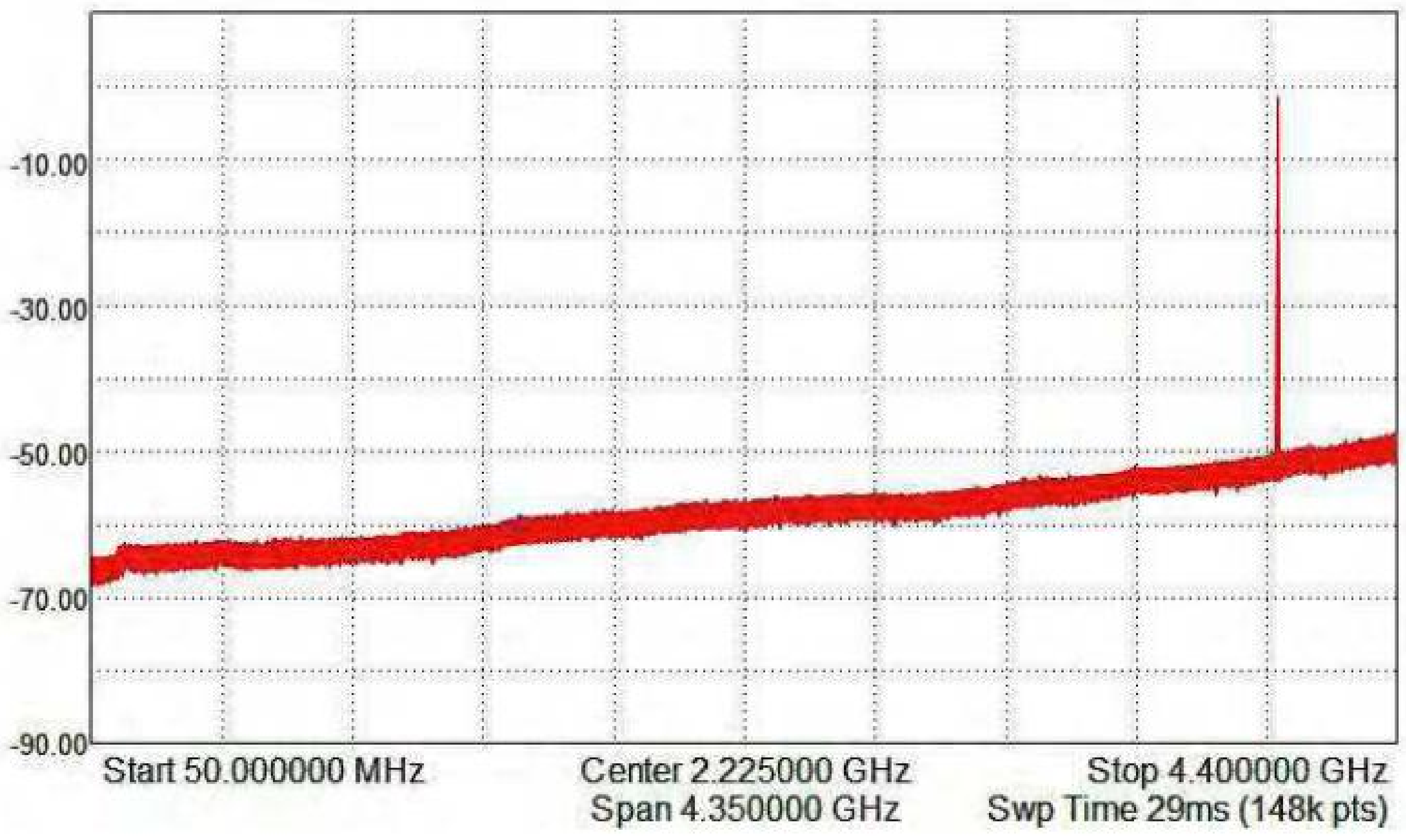


Fig.6: the output frequency now set to 4GHz.

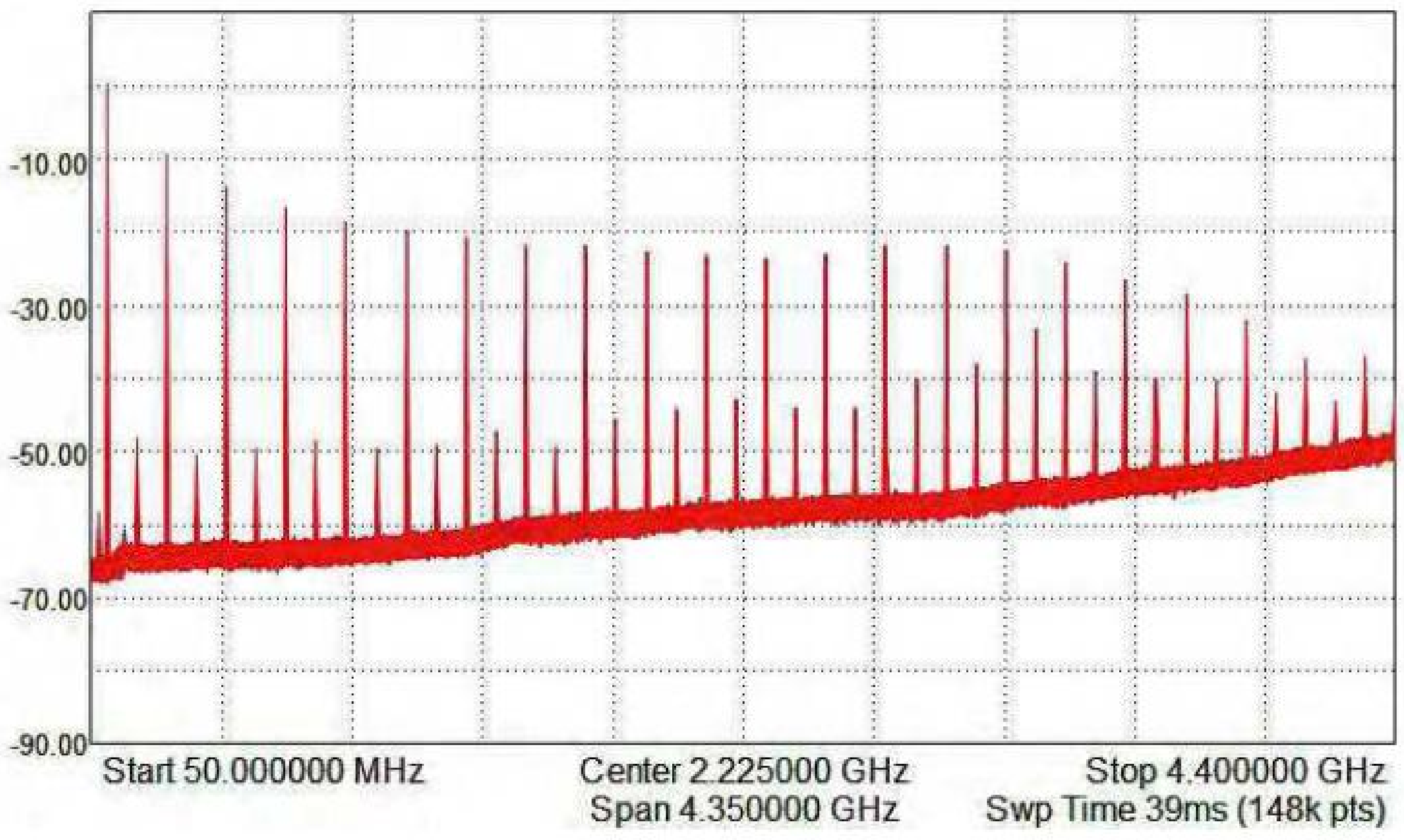


Fig.7: setting the module to an output frequency of 100MHz produces a large number of spurs at the harmonic frequencies (ie, multiples of 100MHz) with varying amplitude.

4. **Step Time:** not clearly explained, but it appears to be for setting the time between steps when sweeping
5. **dB Set:** see below

When you press the OK button (S4) to select this last option, you get a screen giving a choice of four RF Power settings: +5dB, +2dB, –1dB or –4dB. These appear to be provided to allow 'fine adjustment' of the module's RF output level.

When I tried checking these output level options with the module's frequency set to 1GHz using my Agilent V3500A power meter, I obtained the following results:

- With the +5dB setting, the meter registered +3.60dBm
- With the +2dB setting, it registered –0.24dBm
- With the –1dB setting, it registered –1.99dBm
- With the –4dB setting, it registered –4.52dBm

These were all measured with the meter connected to the RF$_{\text{OUT+}}$ connector, using a very short (<20mm) SMA-SMA coupler. So the reference (0dB) level appears to be around –1dBm, and while these settings are not particularly accurate, they give you the ability to adjust the unit's output level somewhat.

The next step was to measure its RF output over the whole frequency range, again using the V3500A power meter. I did these measurements again using the SMA-SMA coupler, connected between the power meter and first the module's RF$_{\text{OUT+}}$ connector, and then the RF$_{\text{OUT-}}$ connector. In each case, the output not being measured was terminated in 50Ω, to hopefully prevent any standing wave disturbances.

As you can see from Fig.2, the level from the RF$_{\text{OUT+}}$ connector is about 4dBm lower than that from the RF$_{\text{OUT-}}$ connector, probably due to the loading from the onboard 51Ω terminating resistor across RF$_{\text{OUT+}}$. But apart from that, both plots are relatively flat, rising slowly by about 2-3dB between 40MHz and 1GHz, and then wobbling a bit to return very close to the 1GHz level at 4.4GHz.

So overall, both outputs were within the range of –4dBm to +4dBm over the entire frequency range. Next, I checked the module's RF output signal purity at several different frequencies, using my Signal Hound USB-SA44B spectrum analyser with the latest version of Signal Hound's 'Spike' software.

The results were reasonably acceptable, bearing in mind that the module's outputs are essentially square waves with significant harmonic content, along with the inevitable spurs you tend to get from any PLL-type synthesiser.

To illustrate this, Fig.3 shows the module's output at 2.5GHz, with the analyser set for a 60MHz span (ie, 30MHz either side of 2.5GHz). The main output is a reasonably clean peak reaching about +1.5dBm in the centre, with two small spurs at about –55dBm around 25MHz either side. So far, it looks reasonably clean.

But now look at Fig.4, which shows what the analyser displays when set to span over the total frequency range from 50MHz to 4.4GHz, with the module still set to 2.5GHz.

Several additional spurs are visible, spaced at about 620MHz apart on either side of the main output, with amplitudes varying between about –6dBm and –18dBm. So the output is not nearly so clean as Fig.3 suggests.

The full-scan plots don't look so bad with the module set to higher frequencies, though. For example, Fig.5 shows the result when the frequency is set to 3.0GHz, while Fig.6 shows a similarly clean plot when it is set to 4.0GHz.

On the other hand, Fig.7 shows the result with a full scan showing what happens when the module is set to produce a 100MHz signal. There's now a virtual 'forest' of spurs, varying in amplitude from –10dBm down to about –49dBm in alternating steps. Not a pretty picture!

Because of the lack of information regarding how to get the module sweeping or stepping from one frequency to another, I gave up trying to test those functions.

Summary

So although the Geekcreit 35MHz-4.4GHz signal generator module is a low-cost, self-contained unit that can generate output signals of around 0dBm (1mW) over that wide frequency range, it does have a few drawbacks and limitations.

One of these is the lack of much information on operating the module, especially with regard to getting it to perform sweeping. Another is the large number of 'spur' components in the outputs, especially when it's generating a frequency below about 1GHz.

That is because its outputs are essentially square waves, rather than the sinewaves that are needed for many signal generator applications. Filtering these to produce a smoother signal is virtually impossible due to the wide range of possible output frequencies; however, external filters could be used if you need cleaner signals at specific frequencies.

And finally, because of its lack of any shielding (especially for the RF generation circuitry around the ADF4351), it would be tough to achieve accurate control over its output level.

But overall, the module would still be useful, for example, if you want to generate digital clock signals over a very wide range of frequencies. Just bear in mind that to use it as the basis of a practical VHF/UHF signal generator, you'd have to add shielding, output filtering and a wide-range output attenuator system.

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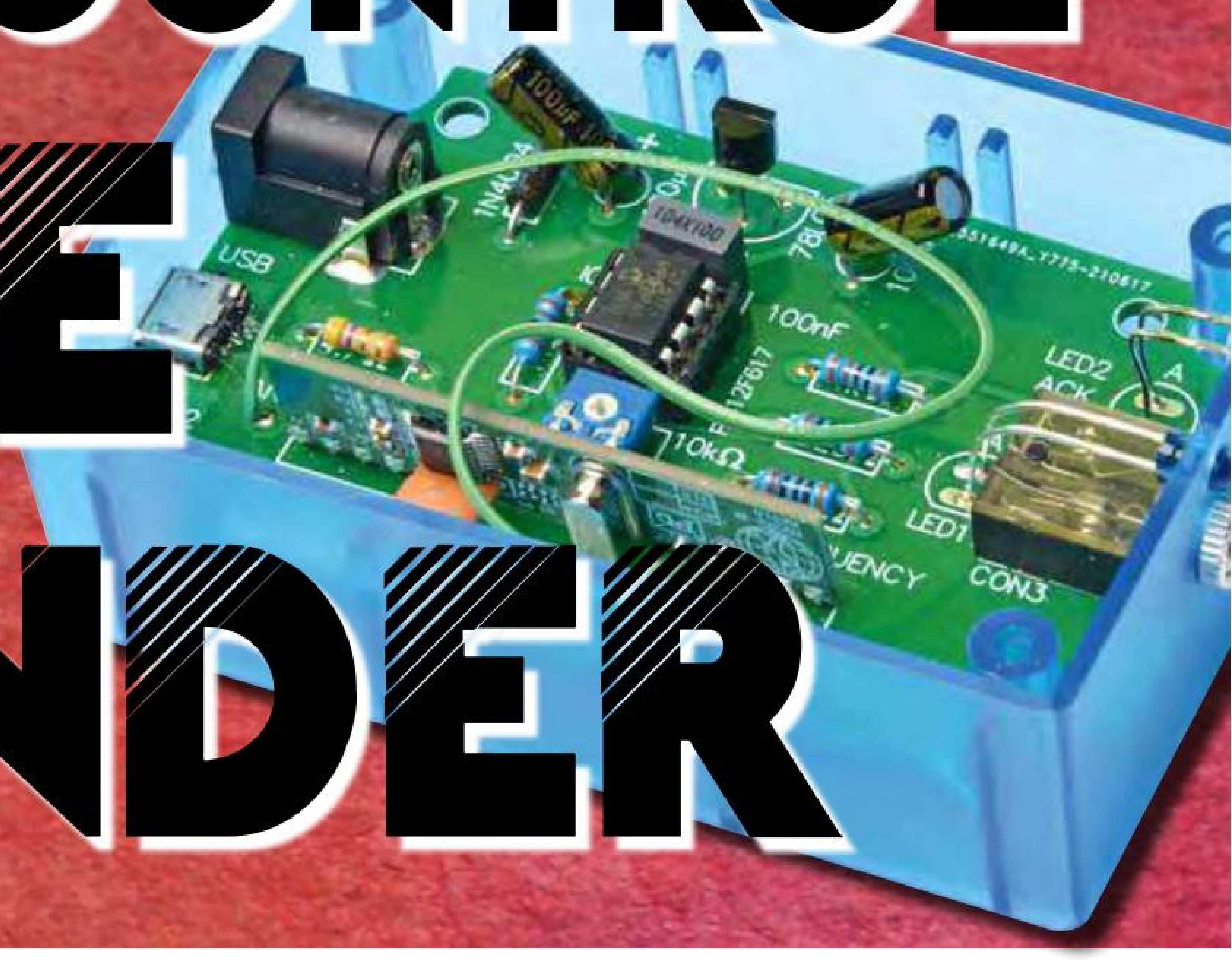
REMOTE CONTROL RANGE EXTENDER



Most remote controls use pulses of infrared light to control equipment. This usually only works reliably up to a few metres and is easily blocked by furniture, people, plants… just about anything. Convert an IR remote to use UHF instead, and it will work at much longer ranges. It will even work when something is between the remote and the device, regardless of where the remote is pointed!

Most of the time, infrared remote controls work very well. But there are times where they are woefully inadequate. This could be because there is an obstruction between the remote control and appliance to be controlled. Or the receiver on the device may be awkwardly placed, making it difficult to direct the infrared beam to it.

Sometimes you might even want to use the remote control in a different room from the appliance being controlled.

Or you might need to position the appliance so that the receiver is not facing where you will usually be located, such as a projector, where it will typically be behind you. Sometimes you can reflect the IR signals using the projector screen, but that doesn't always work reliably.

Regardless of why the IR signal doesn't work well, this device is a great solution. It allows you to convert the infrared remote to transmit using UHF radio signals rather than infrared light. Another small box positioned in front of the infrared receiver on the appliance picks up these radio signals and transmits IR directly into the device's receiver.

Note that if you have more than one appliance to be controlled, you could convert all their remotes to transmit on UHF and use a single UHF-to-IR converter to relay the signals to all those devices. That's provided the appliances are in the same vicinity, so that the light from a single transmitter can reach all their receivers.

Concept

Fig.1 shows the general arrangement for the *Range Extender*. Fig.1(a) shows how the IR-to-UHF Converter works, while Fig.1(b) shows the UHF-to-IR Converter.

The IR-to-UHF Converter monitors the signal that would normally be fed to the IR LED. When a button on the remote control is pressed, it produces a ~36kHz modulated signal to drive that LED. IC1 instead demodulates that signal, and its output (waveform B) is shown in scope grabs Scope 1 and Scope 2 (which can be seen overleaf, with the other scope grabs).

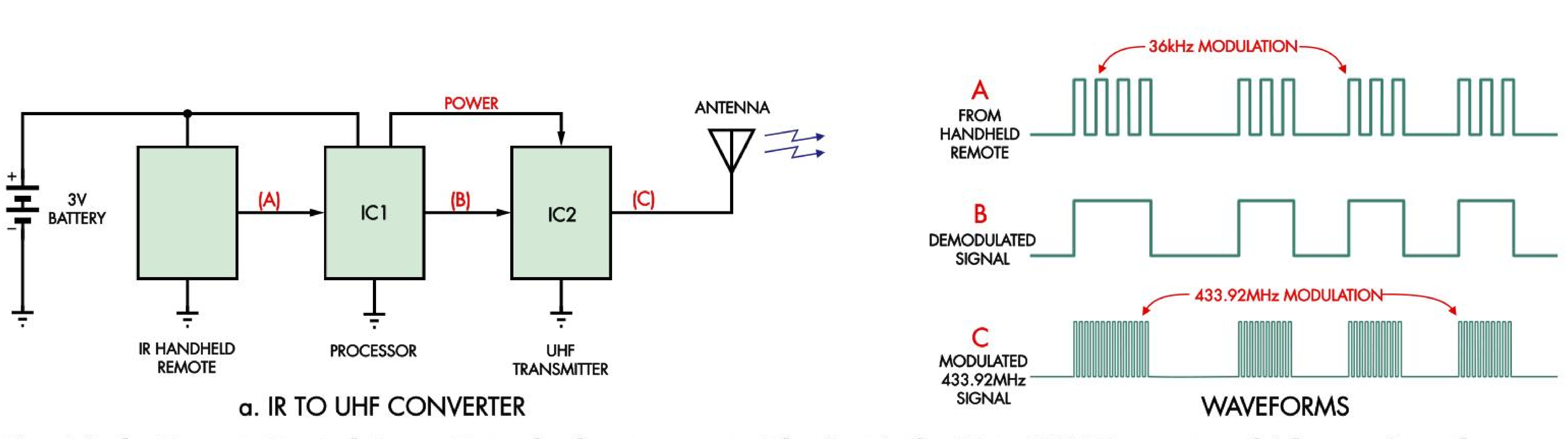
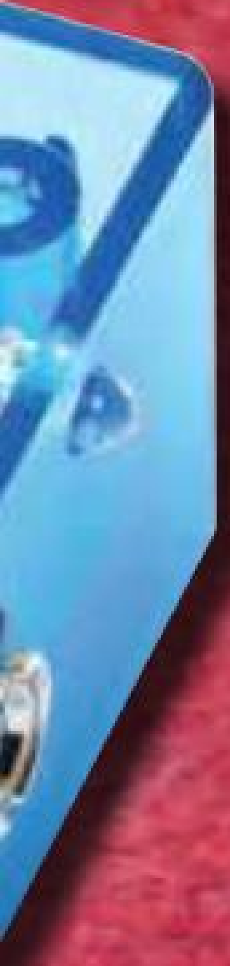


Fig.1(a): the Remote Control Range Extender has two parts. The first is the IR-to-UHF Converter which runs from the remote's battery and converts its IR LED drive signal to a UHF transmission. The second is the UHF-to-IR Converter which picks up those UHF signals and drives an infrared LED with appropriate modulation to control the appliance(s).



IR-to-UHF Converter

- Transmission range: 25m through one weatherboard and Gyprock wall
- Signal delay: 56µs
- UHF transmitter power-down period: 600ms after the last signal
- Standby current: 80nA typical at 3V supply (90nA measured)
- Operating current: 8mA average during transmission

UHF-to-IR Converter

- Valid transmission detection: requires 3ms minimum quieting period
- Acknowledge LED lighting: 654ms time-out after a valid signal
- Modulation frequency: 32.4kHz to 41.4kHz in 32 steps
- Modulation duty cycle: 33.3%
- Current consumption: close to 50mA during signal reception
- IR transmission range: typically 2m to appliance receiver

AUTO SET
COMPUTER
HDMI
VIDEO
S-VIDEO
COMPONENT
ENTER
MENU
SCREEN
KEYSTONE
INFO.
FREEZE
AV MUTE
P-TIMER
LAMP
D.ZOOM
VOLUME
PAGE
IMAGE
MUTE
Panasonic
PROJECTOR

BY JOHN CLARKE

'Demodulation' converts the series of brief 36kHz pulses to a signal that's high when the pulses are present and low otherwise.

When IC1 detects it is receiving a signal, it powers the UHF transmitter (IC2) and sends the demodulated signal to the UHF transmitter's input. The result is that the UHF transmitter produces a 433.92MHz modulated signal to the transmitting antenna. This is waveform C.

So overall, the original 36kHz modulated signal is converted to a 433.92MHz modulated signal for wireless transmission.

The corresponding UHF-to-IR Converter has a UHF receiver (RX1) that provides the demodulated waveform, shown as waveform D. This matches the B waveform – see Scope 3. Processor IC1 on the second board then uses a new 36kHz carrier to produce a modulated waveform, waveform E, that matches the original waveform A, as shown in Scope 4 and Scope 5.

This modulated signal then drives an infrared LED that sends the signal onto the appliance(s) via their onboard IR receivers.

Note that 36kHz is a typical modulation frequency used in infrared remote controls. You can adjust the modulation frequency of the final infrared output to match that of the original remote control, since the remote control could use another frequency between about 32kHz and 41kHz.

Overall, the original handheld remote signal is duplicated at the output of the UHF-to-IR Converter. The appliance receiving the signal is none the wiser that any processing has occurred.

Previously

Note that we published a similar project named *Add a UHF link to a universal remote control* (*PE*, August 2014). While that project is still valid, this one has a much smaller transmitter circuit that can be fitted into small infrared remote controls, unlike the one from 2013.

This became apparent when we tried to install our earlier design inside a small remote control for an LCD projector. There just wasn't any room for it. Subsequently, the entire IR-to-UHF circuit has been redesigned using surface mount components.

Instead of using a large pre-built UHF transmitter module, we use a very small UHF transmitter IC with a few discrete components.

Remote's battery life

One question that arises is what happens to the battery life of the modified remote. Will the battery be flattened in a short time when the UHF transmitter circuitry is added?

We have made sure that there will be a negligible effect on battery life by keeping the circuitry in a sleep mode when the remote is not being used. A typical infrared remote control draws about 1-2µA from the battery continuously and around 10-20mA during infrared transmission. The UHF transmitter's added power draw has almost no effect on these figures.

With the IR-to-UHF Converter installed, we measured the standby

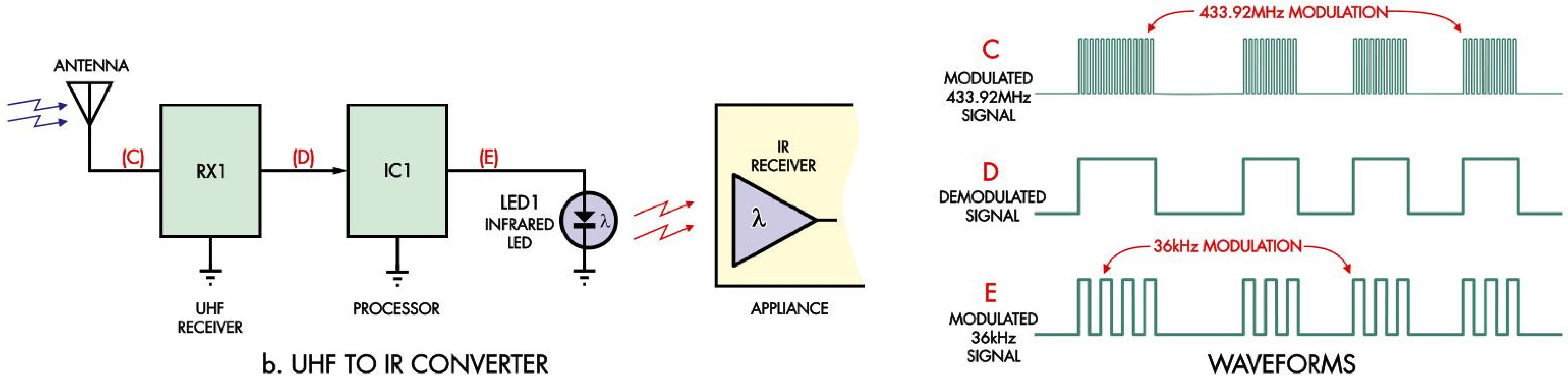


Fig.1(b): the waveforms at right, both here and in Fig.1(a) opposite, show how the original IR LED drive signal is demodulated, then remodulated to 433.92MHz, then demodulated, and then finally remodulated to around 36kHz to drive the IR LED.

A real soldering challenge!

One of the main goals of this design was for the UHF transmitter to be tiny enough to fit inside just about any remote control case. That rules out using a pre-built UHF transmitter module, and due to the relatively high frequencies involved, the components need to be small. **Very** small.

This project uses by far the smallest components we've ever specified in a design.

The 68nH inductor comes in a metric 0603 SMD package (imperial 0201) – that's 0.6 x 0.3mm! Unless you have excellent vision, it will just look like a dot to you (if you can see it at all). And the metric 1206 SMD inductors (imperial 0402) aren't all that much bigger at 1.2 x 0.6mm.

Soldering these devices is a challenge, to put it mildly. If you decide to go ahead, we suggest you purchase at least 10 of each (hey, they're cheap!). That way, if you mangle or lose them, you can grab another one and try again.

Even the larger (by comparison) devices on this board are a little tricky to solder because it's so packed with components – again, to keep it small and also so it can transmit 434MHz signals efficiently.

Besides being a useful little device to build, if you have reasonable SMD soldering skills and want to push yourself to achieve the next level of skill, assembling the transmitter module described here would be a great way to do that.

---

current increasing by a mere 90nA (0.09µA)! The current drain when a button is pressed is essentially unaltered and possibly even a little less than before, as the remote's IR LED is not used and replaced by UHF transmission, which is on average 8mA when active.

By the way, we measured the 90nA figure by connecting a 100kΩ resistor in series with the device's supply and shorting it out until it went into sleep mode. We then measured 9mV across this resistor, which equates to 90nA (9mV ÷ 100kΩ).

Receiver

The companion UHF-to-IR Converter is housed in a small plastic case. One end of the case has a red acknowledge LED and an IR LED to re-transmit the received UHF signal as an IR signal. There is also a 3.5mm jack socket to allow the connection of an external IR LED via a cable.

This device either draws power from a 9-12V DC plugpack or from USB 5V. The circuit draws a maximum current of 50mA when transmitting, so any 9-12V DC plugpack or USB power source should be suitable.

Circuit details

Fig.2 shows the circuit of the IR-to-UHF Converter that's designed to be built into the remote control. It comprises a PIC10LF322 microcontroller (IC1), a MICRF113 UHF transmitter (IC2) and associated components.

IC1 monitors the infrared LED drive signal originally used to drive the infrared LED. The handheld remote output will drive either low or high to power the LED.

An open-collector driver transistor or MOSFET in the remote control IC is normally used. This output requires a pull-up resistance to turn it into a digital signal for sensing, which is supplied by a MOSFET we enable inside IC1.

A 1kΩ pull-down resistor is shown on the circuit, but this is only required if the remote control has an open-collector (or open-drain) output that drives high to power the LED. We will describe how to check for this later.

IC1 converts the LED drive modulation (typically 36kHz) into a demodulated output at pin 4. That pin goes high when a modulated signal is present and low when the modulation is absent.

IC2 is a UHF transmitter that sends digital data using two different carrier wave amplitudes. This is known as Amplitude Shift Keying (or ASK). For our purposes, there is no UHF transmission when the digital signal is low (near 0V) and a 433.92MHz carrier transmission when the digital signal is high (near 3V).

IC1's demodulated signal at pin 4 is suitable for driving IC2 at its ASK input (pin 6). Note that the pin 3 output of IC1 drives the supply input for IC2, at its pin 3. This way, IC2 can be shut down when not needed, drawing no power at idle.

The transmission frequency is set using a crystal oscillator that is multiplied by 32 within IC2 to produce the UHF carrier. So the 13.56MHz crystal gives a carrier at 433.92MHz. This matches the carrier frequency used in most UHF ASK transmitter/receiver modules that are available for low-power UHF data transmission.

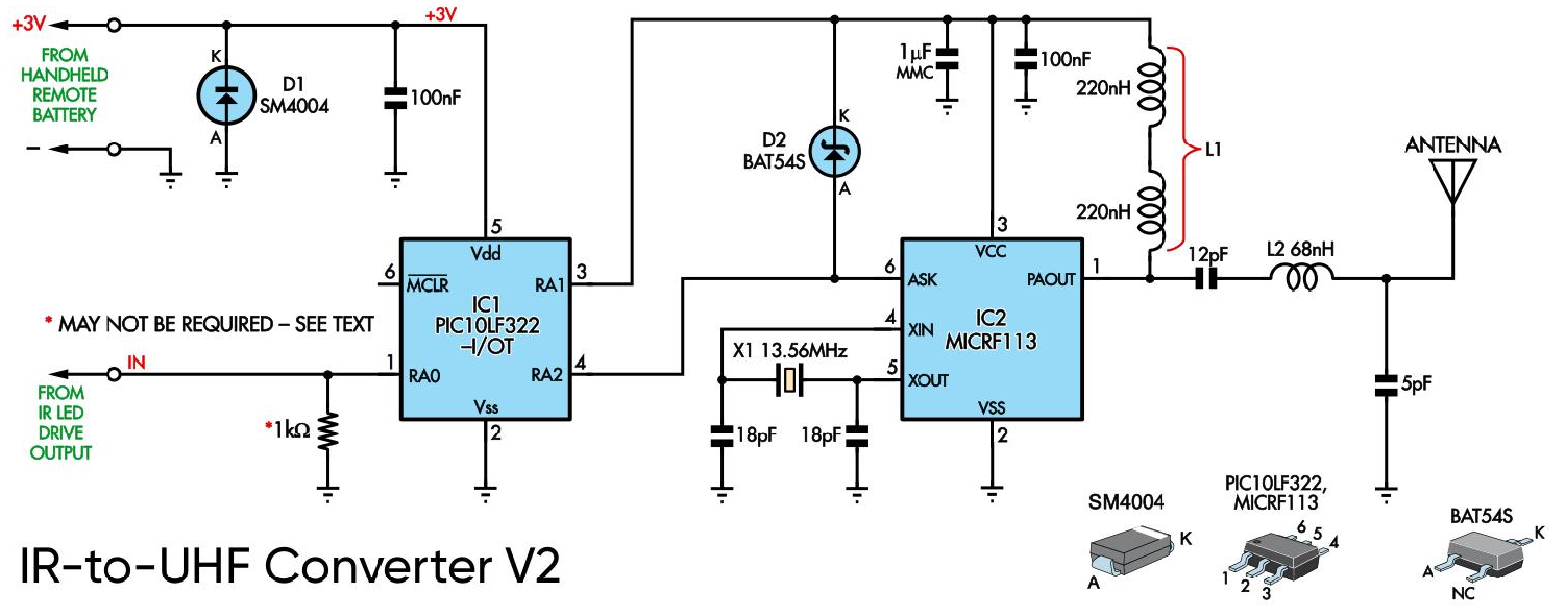


Fig.2: the IR-to-UHF Converter section circuit deliberately uses few components to make the PCB as small as possible. It's powered by the typically 3V supply of the remote control (from two 1.5V cells). IC1 demodulates the drive signal that would normally go to an infrared LED. When it detects a button press, it powers up UHF transmitter IC2 and feeds it the demodulated signal that is then radiated by the antenna at 434MHz.

The MICRF113 and its associated components are tiny, fitting in a much tighter space than most pre-built UHF transmitter modules that are available.

The supply current for IC2's RF output stage is via two series-connected 220nH inductors, also acting as a 440nH driver load. The following 12pF series capacitor and 68nH inductor plus the 5pF capacitor to ground act as a filter that removes second and third harmonics from the UHF signal before it passes to the antenna.

We mainly use two 220nH inductors instead of one 470nH inductor because we found suitable 220nH inductors easier to source. Any inductor used in the circuit must have a self-resonance (SR) frequency above 433.92MHz; otherwise, it will not function as an inductor at that frequency.

Power for IC2

IC2's power rail at pin 3 is bypassed with a 1μF ceramic capacitor, while a 100nF capacitor bypasses the output stage supply. These two capacitors are essentially in parallel but are at different locations on the PCB so that the supply for each part is bypassed directly at its supply connection.

We include schottky diode D2 between the ASK signal and the IC2 supply to boost the supply whenever the IC is transmitting. The pin 3 output drops in voltage when supplying current; and the current flowing from pin 4 of IC1 via diode D2 assists in maintaining a stable supply voltage for IC2.

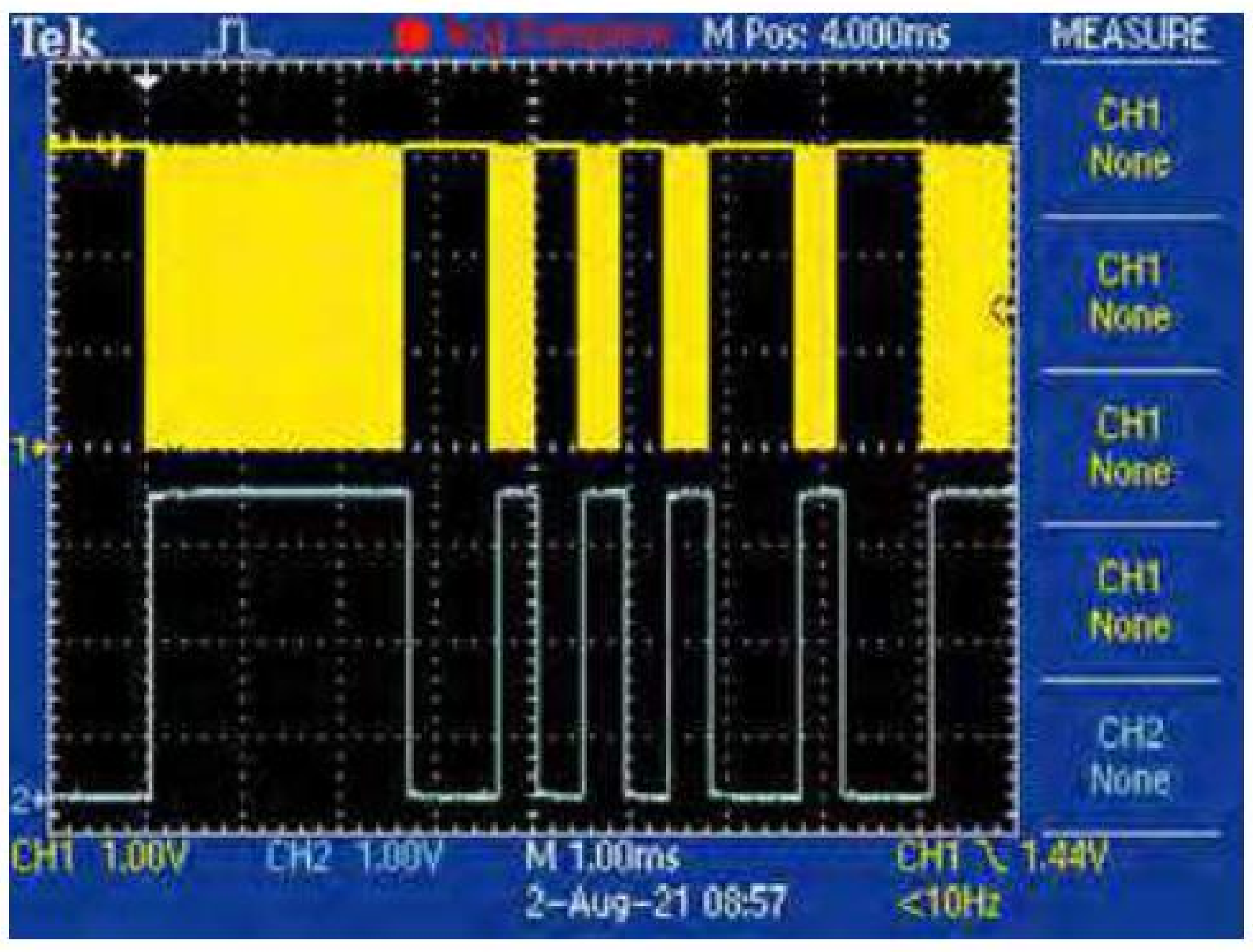
While IC2 can operate down to 1.8V, it's best to keep its supply voltage as close as possible to the 3V from the remote battery for the best efficiency.

IC1's supply is bypassed by another 100nF ceramic capacitor. Diode D1 is included in case the cells in the remote are inserted the wrong way around, causing a reverse polarity to be applied. In this case, D1 will conduct and reduce the reverse voltage applied to IC1, preventing it from being damaged (at least in the short term).

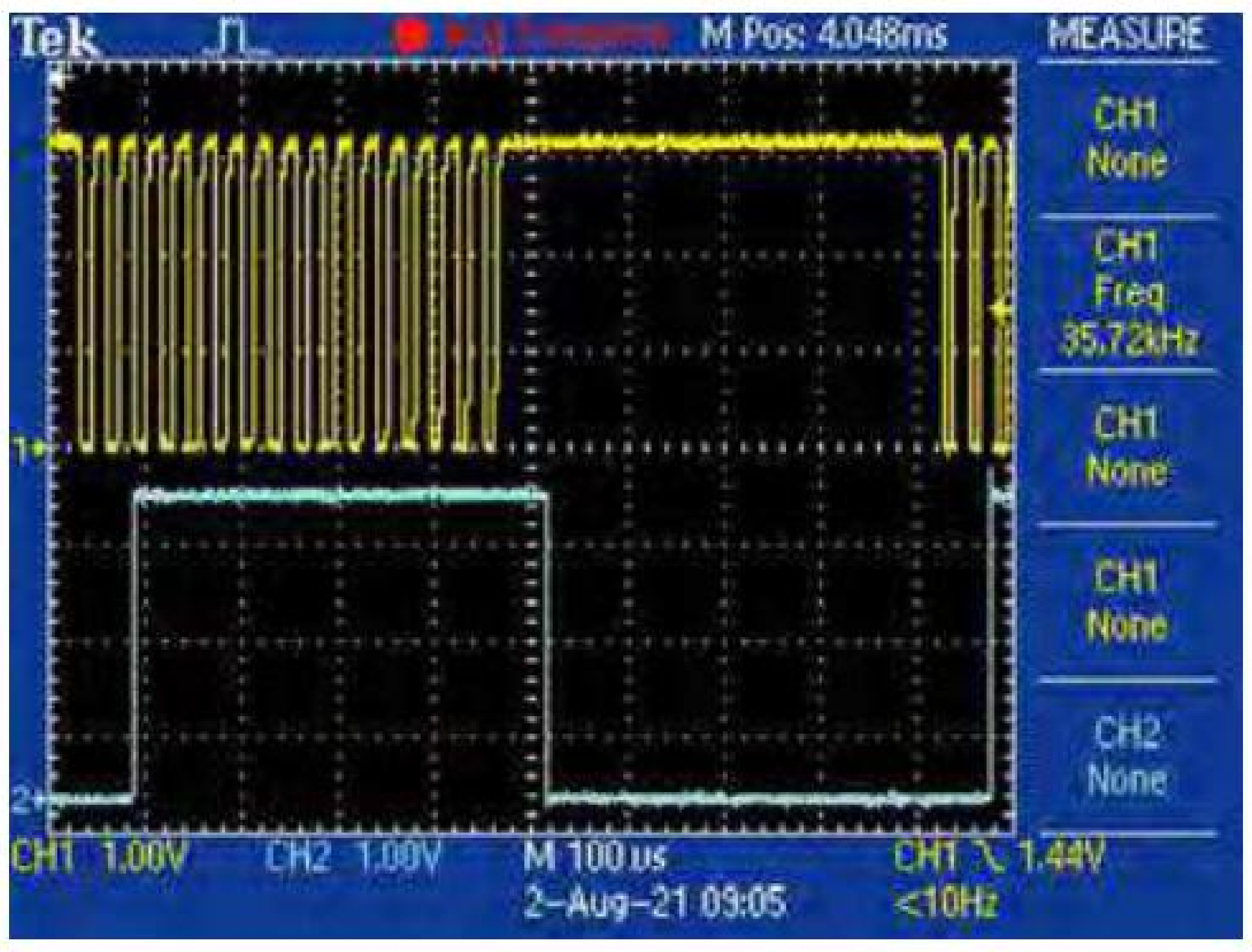
UHF-to-IR Converter

The UHF signal needs to be detected and converted back to a stream of infrared pulses to control the appliance being operated. The UHF-to-IR Converter circuit is shown in Fig.3, and comprises UHF receiver RX1, a PIC12F617 microcontroller (IC1) and an infrared LED (LED1).

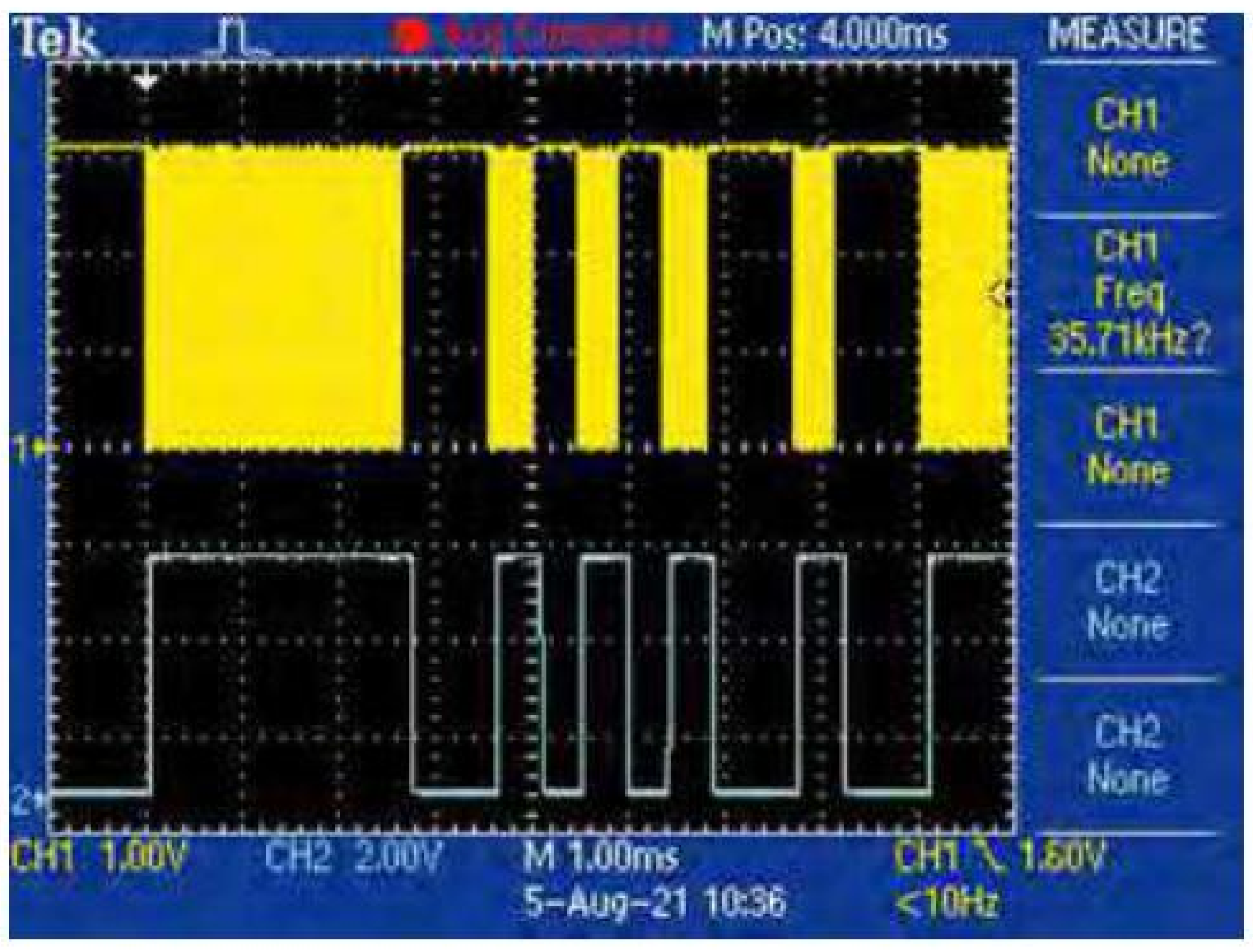
The circuit is powered via either DC socket CON1 or micro-B USB socket CON2. The UHF receiver is powered continuously, ready to receive a transmission from the IR-to-UHF Converter in the handheld remote.


Tek
M Pos: 4.000ms
MEASURE
CH1 None
CH1 None
CH1 None
CH1 None
CH2 None
CH1 1.00V
CH2 1.00V
M 1.00ms
2-Aug-21 08:57
CH1 ╲ 1.44V
<10Hz

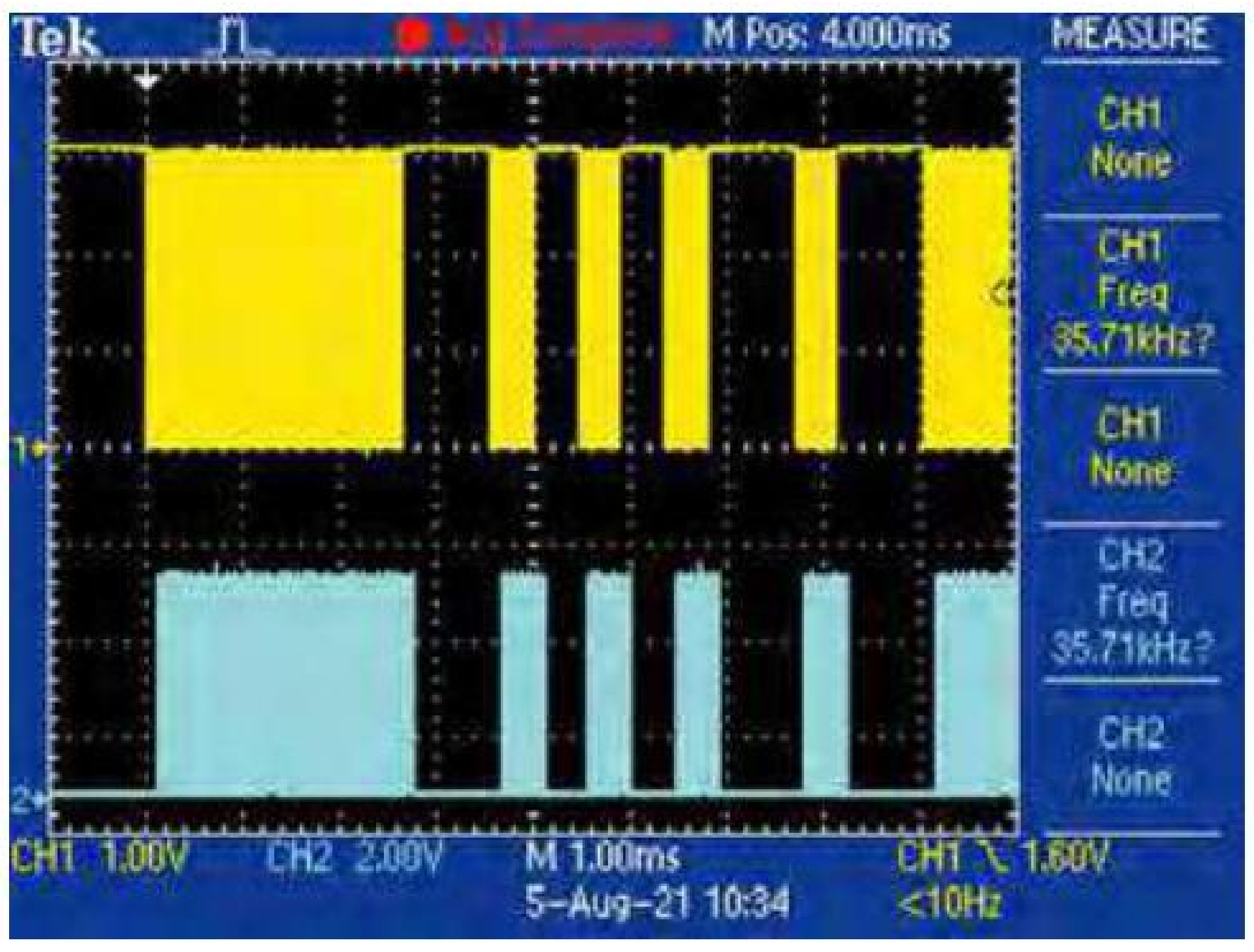
Scope 1: the top yellow trace is the infrared LED drive signal from the remote control, applied to pin 1 of IC1. This is a series of 36kHz pulses. The lower blue trace shows the output of IC1 at pin 4 that drives the ASK input (pin 6) of the MICRF113 434MHz transmitter (IC2). This signal is high whenever there is a 36kHz signal at the input and low otherwise.


Tek
M Pos: 4.048ms
MEASURE
CH1 None
CH1 Freq 35.72kHz
CH1 None
CH1 None
CH2 None
CH1 1.00V
CH2 1.00V
M 100µs
2-Aug-21 09:05
CH1 ╲ 1.44V
<10Hz

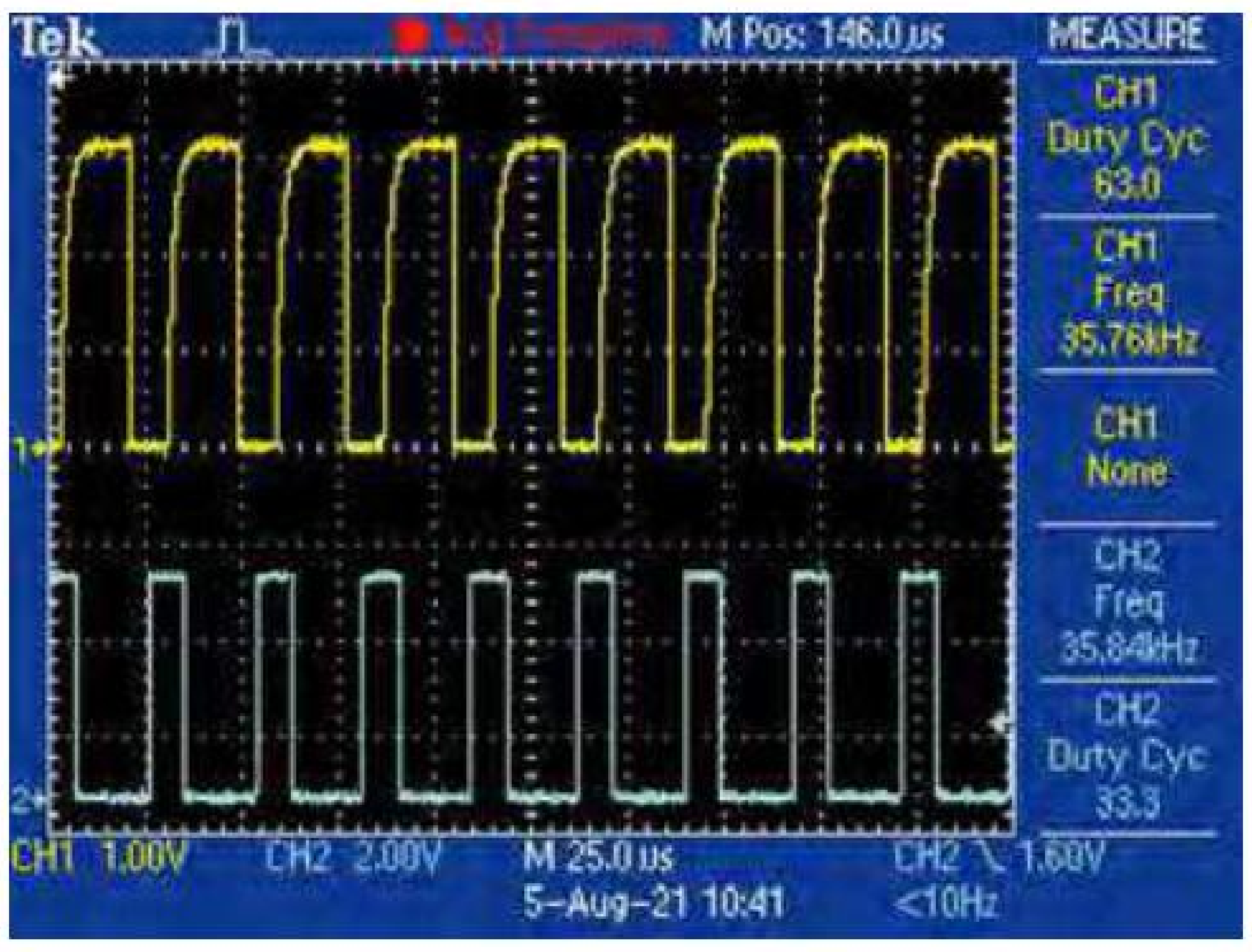
Scope 2: this is the same capture as Scope 1 except with a faster timebase, so the 36kHz modulation is visible. Note the delay of about 56μs between IC1 receiving the 36kHz pulses and producing the demodulated pulses at its output. This does not distort the signal because it is symmetrical.


Tek
M Pos: 4.000ms
MEASURE
CH1 None
CH1 Freq 35.71kHz?
CH1 None
CH2 None
CH2 None
CH1 1.00V
CH2 2.00V
M 1.00ms
5-Aug-21 10:36
CH1 ╲ 1.60V
<10Hz

Scope 3: the top yellow trace shows the IR drive signal from the handheld remote as in Scope 1, but the lower trace is the output from the UHF receiver in the UHF-to-IR Converter, ie, after it has passed over the wireless link.


Tek
M Pos: 4.000ms
MEASURE
CH1 None
CH1 Freq 35.71kHz?
CH1 None
CH2 Freq 35.71kHz?
CH2 None
CH1 1.00V
CH2 2.00V
M 1.00ms
5-Aug-21 10:34
CH1 ╲ 1.60V
<10Hz

Scope 4: the top yellow trace is the infrared LED drive signal from the original infrared remote, while the lower blue trace is the IR LED drive signal in the UHF-to-IR Converter. The two waveforms are essentially the same except for the slight delay in the second trace, and the different voltage levels due to the UHF-to-IR circuit being powered from 5V instead of 3V. The signal inversion is of no consequence.


Tek
M Pos: 146.0µs
MEASURE
CH1 Duty Cyc 63.0
CH1 Freq 35.76kHz
CH1 None
CH2 Freq 35.84kHz
CH2 Duty Cyc 33.3
CH1 1.00V
CH2 2.00V
M 25.0µs
5-Aug-21 10:41
CH2 ╲ 1.60V
<10Hz

Scope5: a zoomed-in version of Scope 4 showing the modulation on both signals. The rise time of the original waveform at the top is slow due to the low pull-up current from pin 1 of the PIC10LF322. The lower blue trace is the IR LED drive from the UHF-to-IR Converter. The frequency has been set to about 36kHz to match the handheld remote. The top trace is inverted compared to the lower trace, as the original LED in the handheld remote was on when the output was low, whereas the IR LED in the UHF-to-IR Converter LED drive is active-high.

With no signal present, the data output from the UHF receiver is just random noise with an amplitude of 5V. In this state, the receiver operates at maximum gain due to its automatic gain control (AGC). When a UHF signal is received, the AGC reduces the receiver's sensitivity so that the detected signal is essentially noise-free. This is fed to the GP5 input (pin 2) of PIC micro IC1.

To determine if a signal is valid, IC1 checks for periods where the data line from the UHF receiver is at 0V for at least 3ms. This indicates that the AGC has reduced the sensitivity of the receiver and that a transmission is occurring.

The data output from the UHF receiver matches that data applied to the UHF transmitter. This data signal, in part, becomes the Acknowledge waveform that drives LED2 via digital output GP0. The 1kΩ resistor limits the LED current to around 3mA.

IC1 drives the IR LED (LED1) from its GP1 and GP2 outputs in parallel to provide sufficient current. The 220Ω resistor limits this current to around 18mA.

The infrared LED drive signal needs to include the same or similar modulation as that used by the original remote. So when the data output from the UHF receiver goes high, the GP1 and GP2 outputs are driven with pulse-width modulated signals. The duty cycle is 33.3%, so they are high 1/3 of the time and low 2/3 of the time.

The GP4 input of IC1 monitors the voltage set by trimpot VR1, connected across the 5V supply rail. Its wiper voltage is converted to a digital value within IC1, allowing the IR carrier frequency to be adjusted to match the original transmitter. The adjustment range is from 32.4kHz to 41.4kHz in 32 steps. Setting VR1 to its mid-position gives 37kHz.

Usually, somewhere near the middle setting is satisfactory, but some devices might require a different carrier frequency to operate reliably.

A second output is provided via a 3.5mm jack socket (CON3) for an external IR LED (if necessary). This IR LED can be mounted near the IR receiver of the appliance(s) which are being operated.

Power from a 9-12V DC plugpack is fed in via diode D1, providing reverse polarity protection. A 78L05 3-terminal regulator then provides a 5V supply for RX1 and IC1. Power via the USB connector is applied to the 5V supply rail via a 4.7Ω resistor. This resistor prevents excess current flow between the REG1 output and the 5V from the USB should be connected.

Construction

The IR-to-UHF Converter PCB is coded 15109212, measures 15mm x 12mm and is available from the *PE PCB Service*. It has components mounted on both sides. Refer to the PCB overlay diagrams, Fig.4a and Fig.4b, to see which parts go where.

Now is the time to program IC1 – the code is available for download from the January 2023 page of the *PE* website: **https://bit.ly/pe-downloads**

Begin assembly by fitting the surface-mount parts on the top side of the PCB. These can be soldered using a fine-tipped soldering iron. Good close-up vision is necessary; you might need a magnifying lens or glasses to see well enough. Fine-point tweezers can help to hold the components in place.

It will be easier to install the two 220nH inductors first. Solder *one* pad and then check alignment. Reheat the soldered pad and move the device if the inductor needs moving before soldering the second pad.

Next, mount the two ICs. IC1 and IC2 are positioned so that the small pin 1 location dot aligns with that on the PCB. When the IC is held with pin 1 at lower left, the writing on the IC top face will be the right way up. IC1 will be marked LF followed by two traceability code numbers. IC2 will have 'F_113' etched on the top face.

Orient the ICs on the PCB with the pin 1 dot at upper left. For each IC, solder one pad first and then check their alignment. Readjust the component positioning by reheating the solder joint if necessary before soldering the remaining pins. Any shorts between pins can be cleared using solder wick to draw up the excess solder (adding flux paste first will help this process).

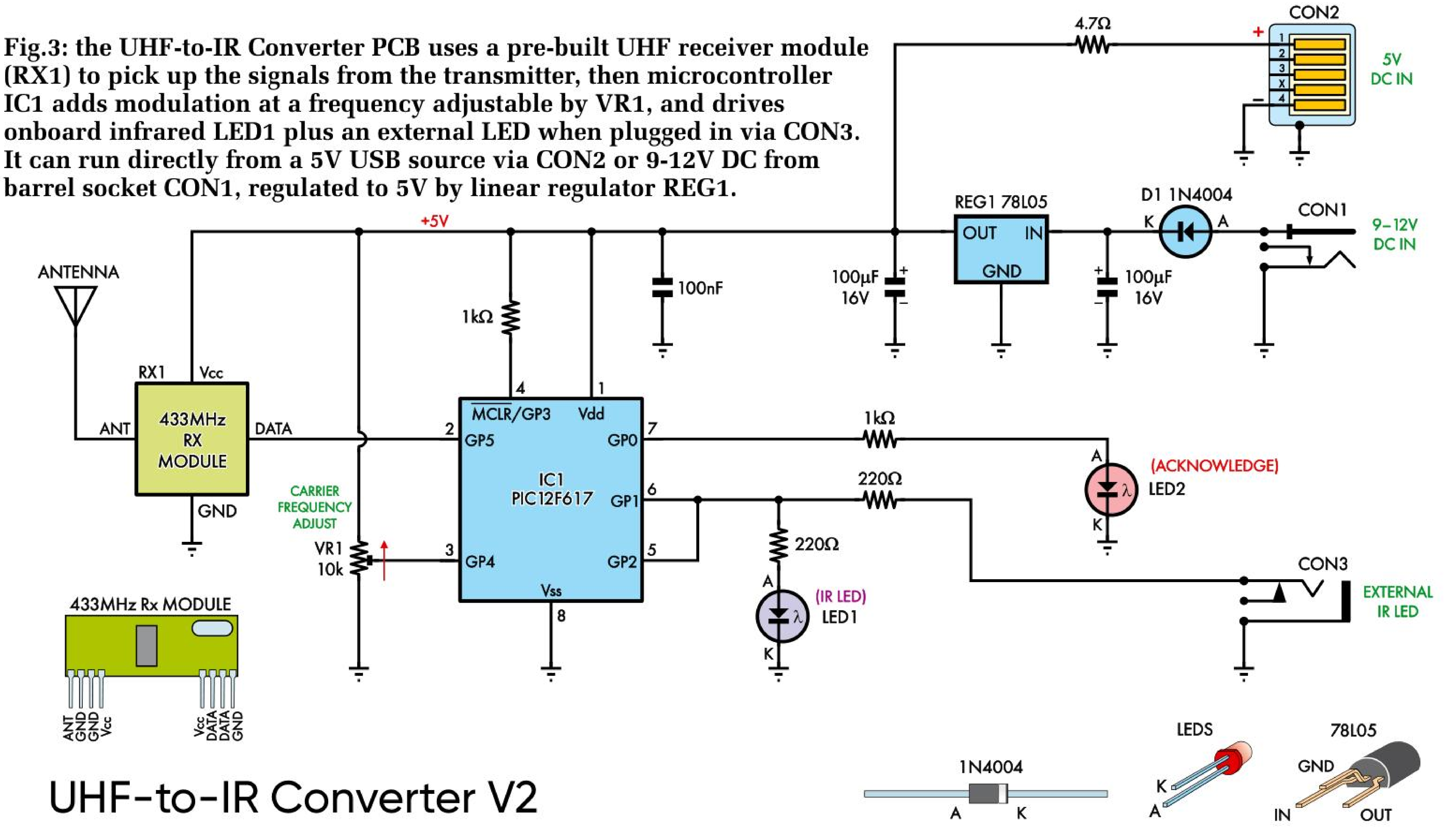
Now diode D2 can be soldered in before fitting crystal X1. Make sure D2 is oriented as shown in Fig.4(a).

You can then install the remaining top-mounted components. Note that many of the capacitors and inductors in surface-mount packages are unmarked, so you will need to rely on the packaging to show what they are and their value. Mount one component at a time to avoid mixing them up.

We are using capacitors and a resistor in slightly smaller M2012/0805 packages compared to the M3216/1206 packages we use elsewhere. This makes it easier to avoid accidentally making solder bridges to adjacent components when fitting them.

It is also possible to lose components, so be careful and, if possible, get spares. SMD resistors and

Fig.3: the UHF-to-IR Converter PCB uses a pre-built UHF receiver module (RX1) to pick up the signals from the transmitter, then microcontroller IC1 adds modulation at a frequency adjustable by VR1, and drives onboard infrared LED1 plus an external LED when plugged in via CON3. It can run directly from a 5V USB source via CON2 or 9-12V DC from barrel socket CON1, regulated to 5V by linear regulator REG1.

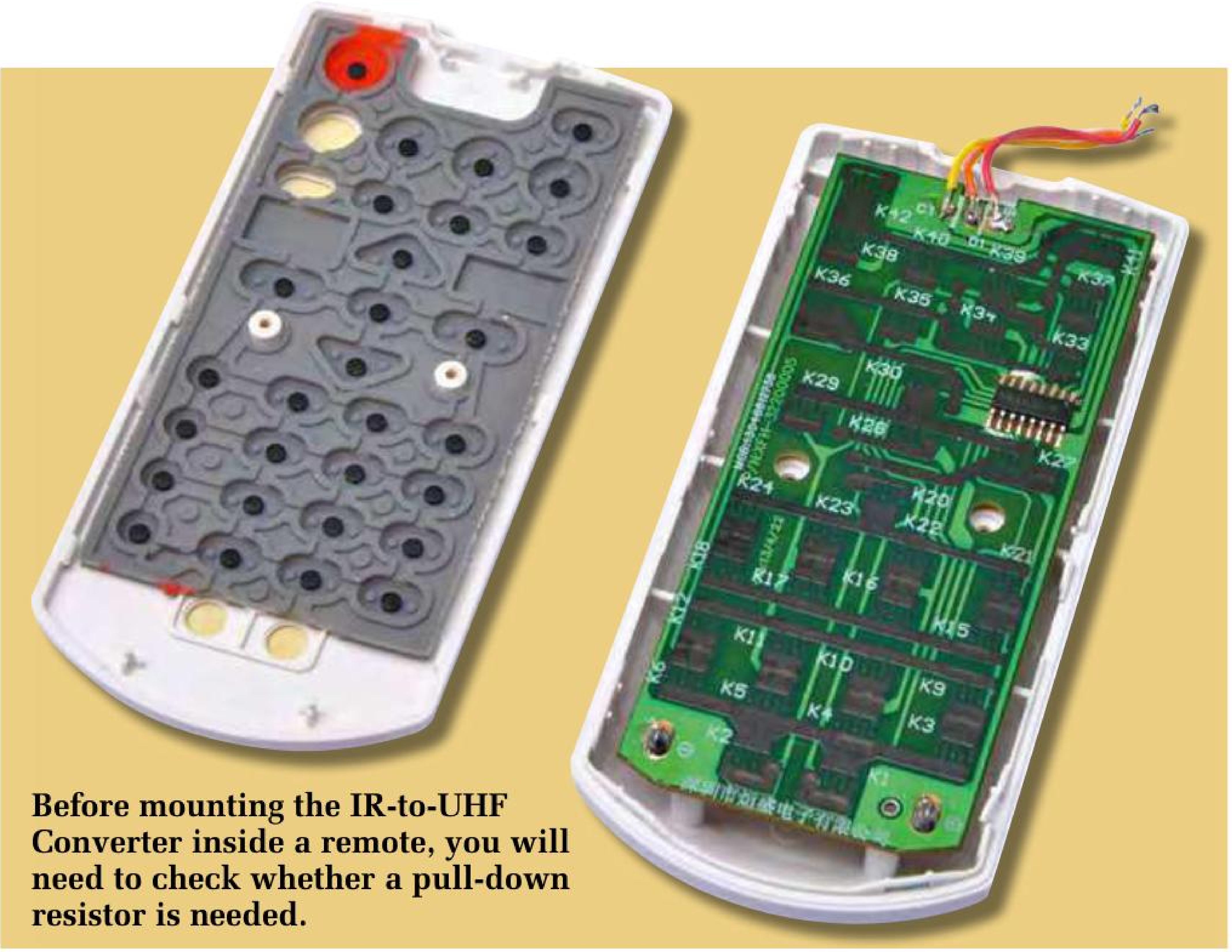


capacitors are generally very cheap and sold in useful sets which are well worth investing in.

Incidentally, we recommend that you mount the 68nH inductor after fitting the 12pF and 5pF capacitors; otherwise, you might accidentally desolder this inductor.

Now turn your attention to the underside of the PCB. There are two 18pF capacitors, one 1kΩ resistor and diode D1. Take care to position the diode correctly, with the cathode stripe, as shown in Fig.4(b). Note that the resistor might not be required, so leave it off for the moment.

If you want to be sure that the components have been soldered correctly, you can trace the connections to the other sections of the PCB to where there should be continuity. For example, pin 3 of IC1 should provide a low resistance reading to pin 3 of IC2. Additionally, check that there are no short circuits between component pins on the PCB that shouldn't be connected.



Before mounting the IR-to-UHF Converter inside a remote, you will need to check whether a pull-down resistor is needed.

Pull-up or pull-down

As mentioned, the handheld remote control might drive its output high or low to turn the IR LED on. The way the LED is driven determines whether you need to install the 1kΩ pull-down resistor. The internal pull-up within IC1 is automatically activated if the pull-down resistor is not fitted.

To determine this, first you will need to open the remote control case. Some remote cases are secured using screws that are easy to spot, but they also could be hidden under the cells. Open the battery compartment and remove the cells to check for screws. Once these are out, open the case by gently working around the sides with a thin implement to separate the two halves.

Once inside, locate the positive and negative battery terminals. To check whether the resistor is needed, it is just a matter of making some measurements with a multimeter.

First, check the resistance between the battery's positive terminal and the anode (+) of the LED. If it is low (less than 30Ω), you can expect that the pull-down resistor is not needed. That is because the cathode of the LED would be pulled down to power the LED.

If the resistance between the cathode (–) of the LED and the negative battery terminals is low (less than 30Ω), that means the LED drive is active-high, so the 1kΩ pull-down resistor is needed.

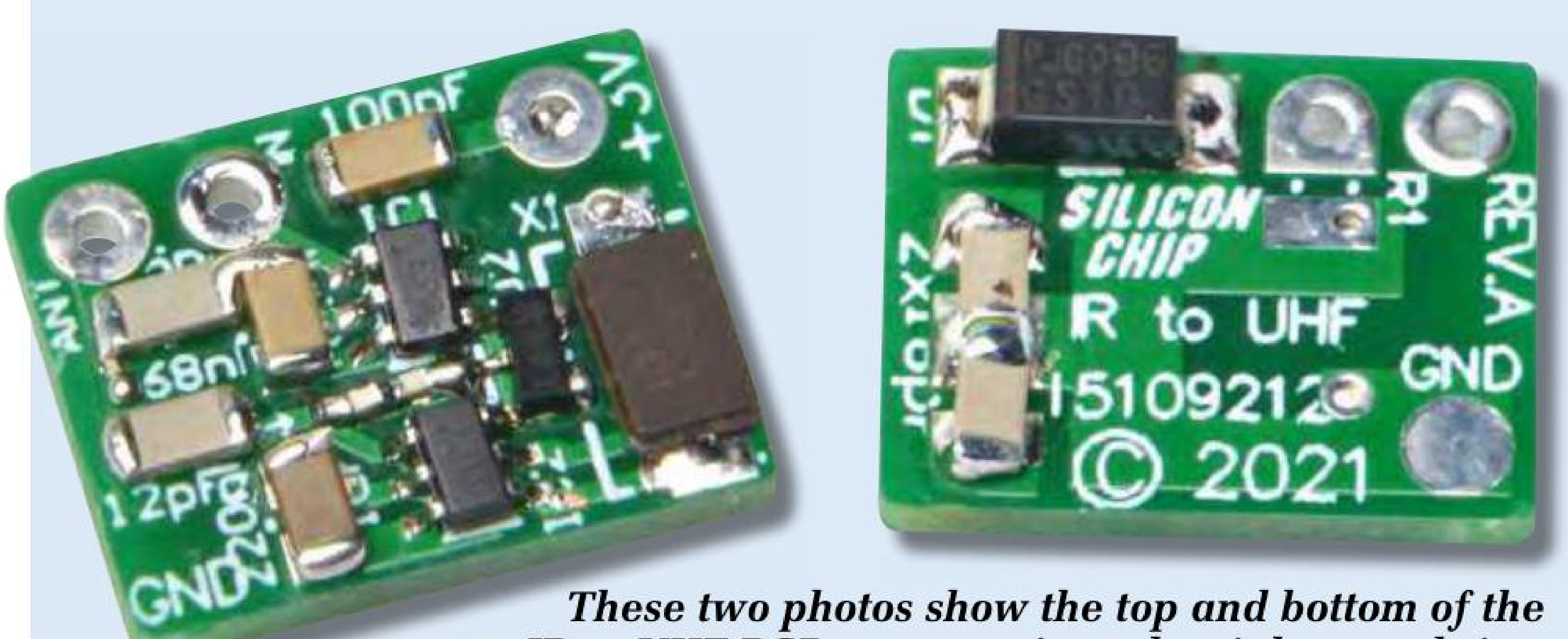
After the pull-down resistor is soldered in place (if needed), the assembled PCB can be mounted in the remote's case. The IR LED should be removed.

Wire up the supply connections: '+' to the +3V on the remote, GND to the 0V terminal and IN to the LED drive pin on the remote's IC (eg, to the pad where the LED was soldered). You might need to trace out the PCB to figure out which one to connect.

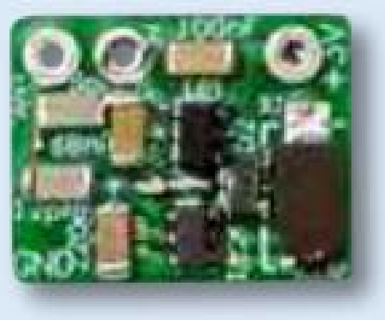
Now place the PCB in a suitable spare space within the remote. Next, solder the antenna wire, and route this around the case in a position where it will not be caught when it is reassembled.

Note that while we specify a 170mm length of antenna wire, the transmission range does not suffer significantly if it is shortened. We found that a 53mm length of antenna wire only reduced the range by 5m compared to the 170mm length.

Finally, clip the case together and reinstall the securing screws if they were present.



These two photos show the top and bottom of the IR-to-UHF PCB at approximately triple actual size.



THIS BOARD SHOWN 200% ACTUAL SIZE FOR CLARITY

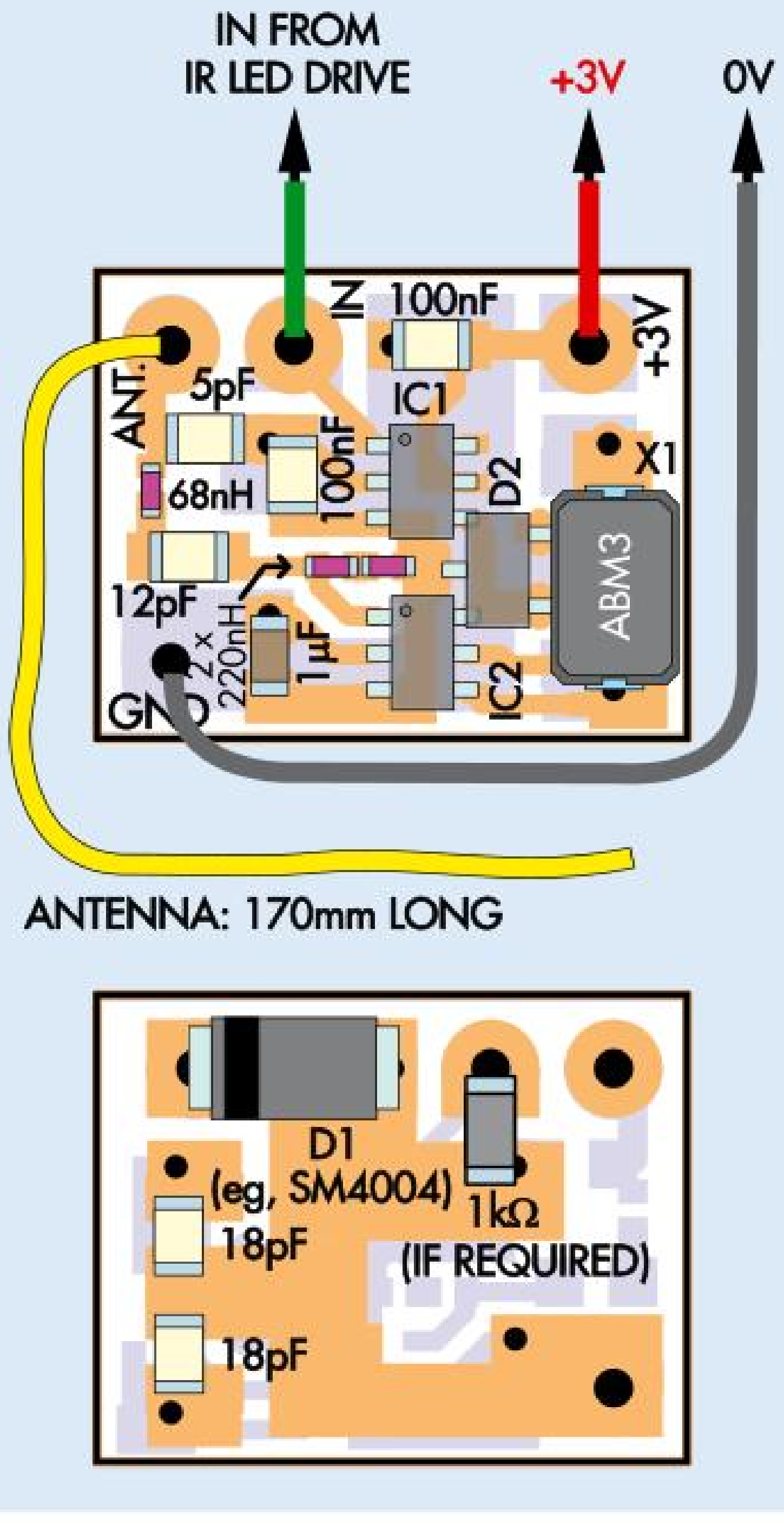


Fig.4 (right): the IR-to-UHF converter PCB is packed so it can fit inside just about any remote control case. Don't worry too much about bridging the pins of IC1 and IC2 when soldering them as that can be fixed quite easily using solder wick and flux paste, but do be careful to orient those ICs correctly and don't mix them up. The 68nH inductor is minuscule, so be careful not to lose it. After soldering it, check for a low resistance reading between the antenna terminal and left end of the 12pF capacitor.

Parts List – Remote Control Range Extender

IR-to-UHF Converter

1 double-sided PCB coded 15109212, 15mm x 12mm, from the *PE PCB Service*
1 13.56MHz surface-mount crystal (X1) **[RS Components 171-0468]**
2 220nH 500MHz inductors, M1005/0402 SMD (L1) **[RS 741-3797]**
1 68nH 1.2GHz inductor, M0602/0201 SMD (L2) **[element14 3386563]**
1 170mm length of light-duty hook-up wire (for the antenna)
1 200mm-length of red hook-up wire
1 200mm-length of green hook-up wire
1 200mm-length of blue hook-up wire

Semiconductors
1 PIC10LF322-I/OT 8-bit microcontroller programmed with 1510921M.HEX, SOT-23-6 (IC1) [download from the January 2023 page of the *PE* website: (**https://bit.ly/pe-downloads**]
1 MICFR113YM6 ASK UHF transmitter chip, SOT-23-6 (IC2) **[RS 177-3314P]**
1 1A SMD diode, DO-214AC (D1) **[SM4004 or GS1G; Altronics Y0174, Jaycar ZR1003]**
1 BAT54S ❶ small signal schottky diode, SOT-23 (D2) **[Altronics Y0075]**
❶ *BAT54, BAT54S, BAT54C, BAT54FILMY and BAT54SFIMLY are all suitable*

Capacitors *(all SMD M2012/0805 size ceramic)*
1 1µF 16V X7R (preferred) or Y5V **[Altronics R8650]**
2 100nF 50V X7R (preferred) or Y5V **[Altronics R8638]**
2 18pF 50V C0G/NP0 **[Altronics R8533]**
1 12pF 50V C0G/NP0 **[Altronics R8527]**
1 4.7pF or 5pF 50V C0G/NP0 **[Altronics R8512]**

Resistors
1 1kΩ SMD M2012/0805 ⅛W (**might not be required**; see text) **[Altronics R1220]**
1 10kΩ to 470kΩ ¼W axial leaded resistor (for testing)

UHF-to-IR Converter

1 double-sided PCB coded 15109211, 79 x 47mm, from the *PE PCB Service*
1 UB5 Jiffy box, 83 x 54 x 31mm
1 lid label, 78 x 49mm
1 433.92MHz receiver module (RX1) [eg, **Jaycar ZW3102, Altronics Z6905A**]
1 PCB-mount barrel socket to suit plugpack (CON1)
1 micro-USB SMD Type-B USB socket (CON2) **[Jaycar PS0922, Altronics P1309]**
1 3.5mm PCB-mount switched jack socket (CON3) **[Jaycar PS0133, Altronics P0092]**
1 8-pin DIL IC socket (for IC1)
1 170mm-length of light-duty hookup wire
1 10kΩ miniature horizontal trimpot (VR1)

Semiconductors
1 PIC12F617-I/P 8-bit microcontroller, DIP-8, programmed with 1510921A.hex (IC1) [download from the January 2023 page of the *PE* website: (**https://bit.ly/pe-downloads**]
1 78L05 5V 100mA linear regulator, TO-92 (REG1)
1 3mm infrared LED (LED1)
1 3mm red LED (LED2)
1 1N4004 400V 1A diode (D1)

Capacitors
2 100µF 16V PC electrolytic
1 100nF 63V MKT polyester

Resistors *(all ¼W 1% thin film axial)*
2 1kΩ
2 220Ω
1 4.7Ω

Optional parts for extended IR transmitter lead
1 3.5mm mono jack plug
1 1m length of single-core screened cable
1 3mm infrared LED
1 100mm length of 3mm diameter heatshrink tubing

UHF-to-IR Converter assembly

The companion UHF-to-IR Converter is built on a double-sided PCB coded 151009211 that measures 79 x 47mm and is available from the *PE PCB Service.* This clips neatly into an 83 x 54 x 31mm UB5 plastic utility box. A 78 x 49mm lid panel label can be attached to this.

Now is the time to program this IC1 – the code is available for download from the January 2023 page of the *PE* website: **https://bit.ly/pe-downloads**

Fig.5 shows the parts layout for this board. Start with the micro USB socket, which is surface-mounted. Align the solder pads with the leads on the connector and solder one of the mounting tabs to the PCB.

Re-check the alignment of the small signal pins before soldering the signal pins and then the remaining tabs. The solder on the mounting tab can be remelted, and the connector realigned if it is not correct.

Check the signal pins for solder bridges; if you find any, clear them using solder wick. Make sure the pins are still soldered to the PCB.

Now fit the resistors. The resistor colour codes can be used as a guide to their values but checking the resistances with a multimeter is *always* a good idea.

Next, mount diode D1, ensuring it is correctly oriented. The capacitors can go in next; only the two 100µF electrolytics are polarised. As well as ensuring their longer leads go to the pads marked with '+' symbols, they must be bent over to clear the lid when the PCB is mounted in its case.

REG1 can then be mounted, followed by the DC socket (CON1), the 3.5mm jack socket (CON2) and trimpot VR1 (set it mid-way now). Next, fit the UHF receiver (RX1), making sure it goes in the right way around.

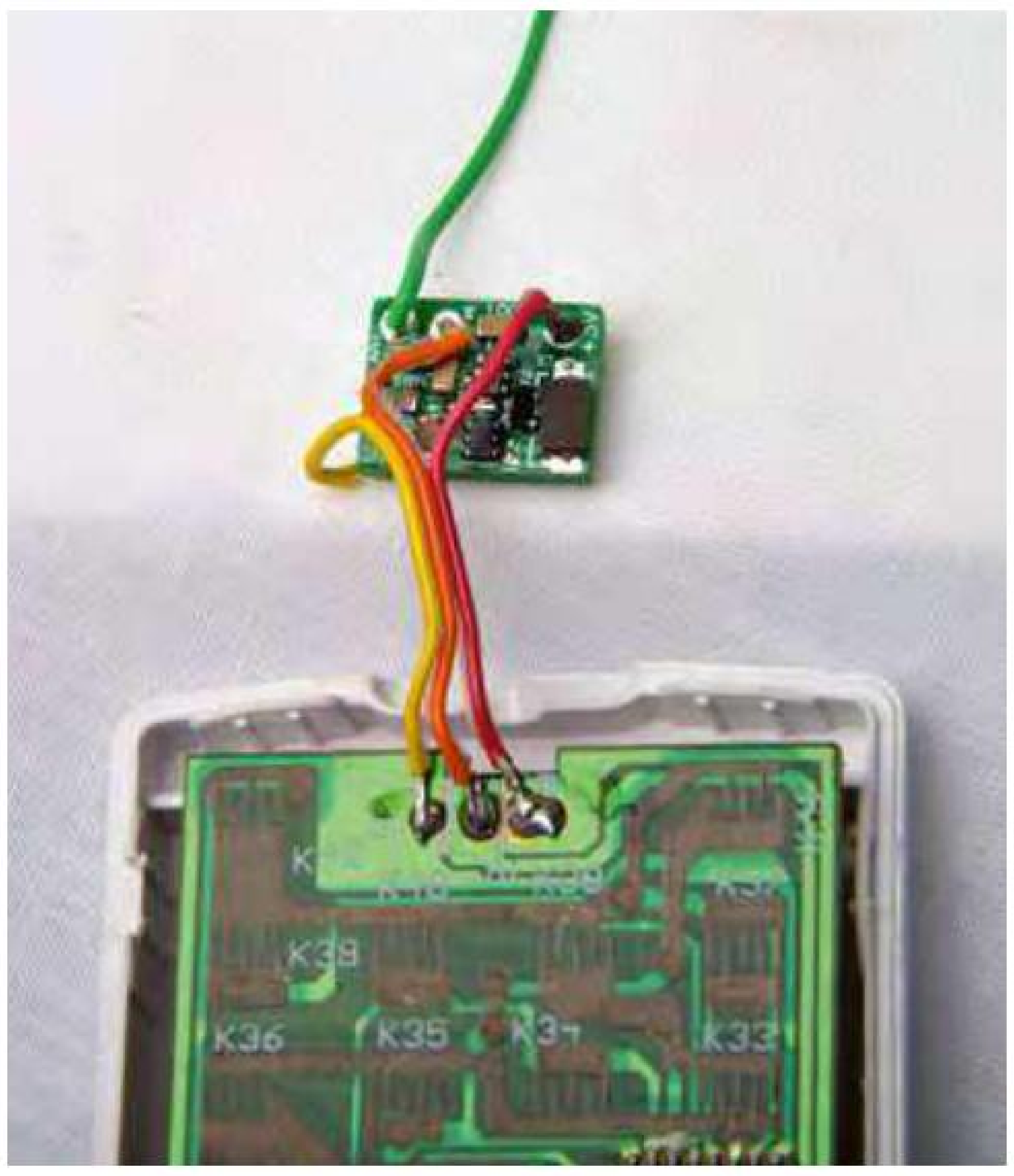
Installing the LEDs

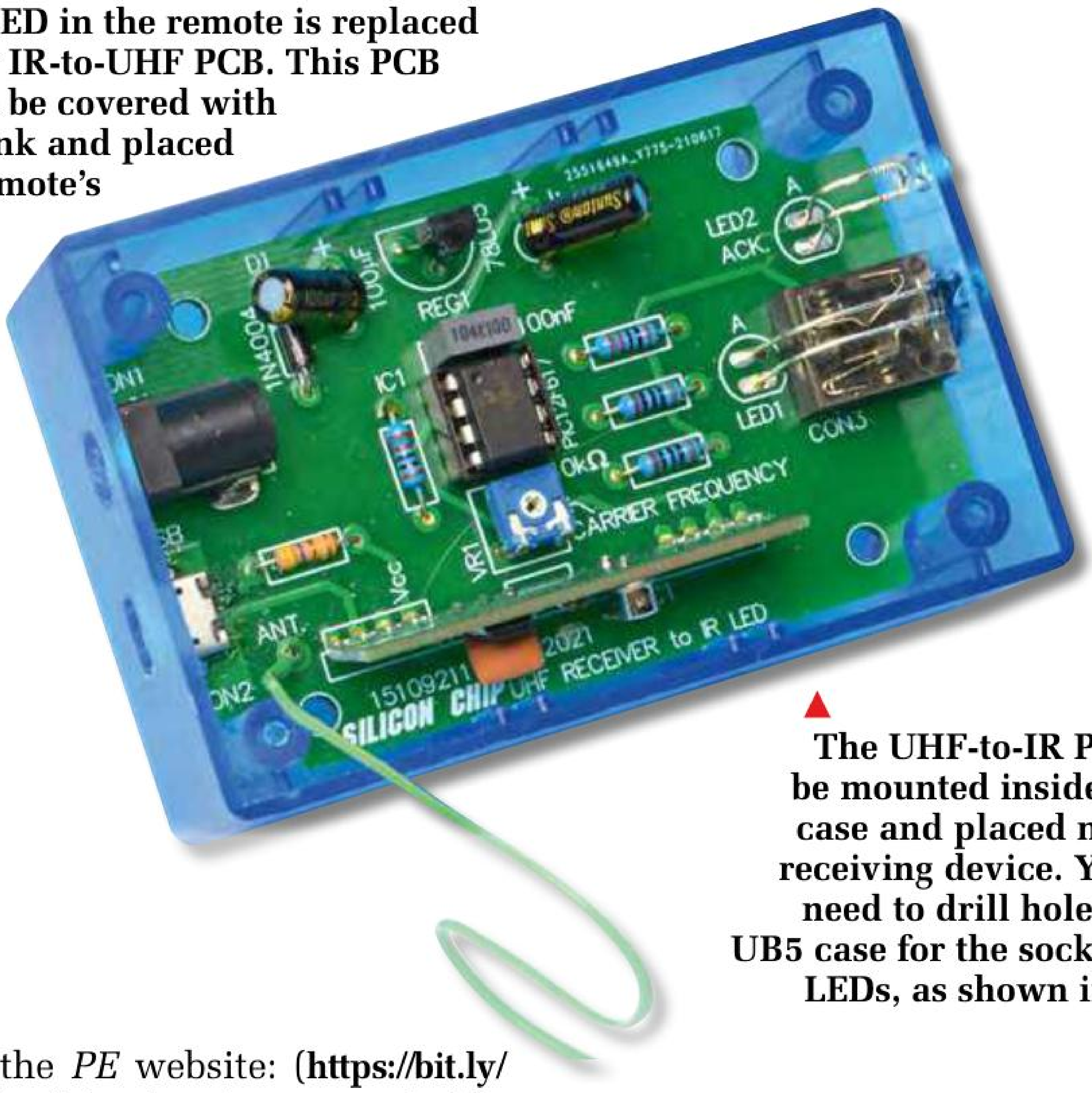
LED1 must be mounted at full lead length (25mm) so that later it can be bent over and its lens pushed through a hole in the side of the box (above the 3.5mm socket). LED2 is mounted with the top of its lens 20mm above the PCB surface. Make sure the LEDs are oriented correctly, with their anode (longer) leads going to the pads marked 'A'.

Now solder in an 8-pin DIL socket for IC1, but do not plug the PIC micro in at this stage. That step comes later after the power supply has been tested. Complete the PCB assembly by fitting the 170mm-long antenna wire made from insulated hookup wire.

Final assembly

The PCB simply clips into the integral ribs of the UB5 case. Before doing this, you need to drill holes in the case ends for the USB socket, the DC socket, the 3.5mm socket and the two LEDs. The drilling diagrams are shown in Fig.6.




1N4004
D1
100µF
REG1
78L05
100nF
IC1
PIC12F617
LED2
ACK
A
LED1
CON3
CARRIER FREQUENCY
VR1
Vcc
ANT.
CON2
15109211
2021
SILICON CHIP UHF RECEIVER to IR LED

◀ **The IR LED in the remote is replaced with our IR-to-UHF PCB. This PCB can then be covered with heatshrink and placed in the remote's housing.**

▲ **The UHF-to-IR PCB can be mounted inside a UB5 case and placed near the receiving device. You will need to drill holes in the UB5 case for the sockets and LEDs, as shown in Fig.6.**

The DC socket hole can be drilled first. This is positioned 6.5mm down from the top lip of the base at the left-hand end.

Start this hole using a small pilot drill, then carefully enlarge it to 6.5mm using a tapered reamer. The 3.5mm socket hole is centred along the horizontal axis at the other end of the case, 10.5mm down from the lip. Again, use a pilot drill to start it, then enlarge it to 6.5mm.

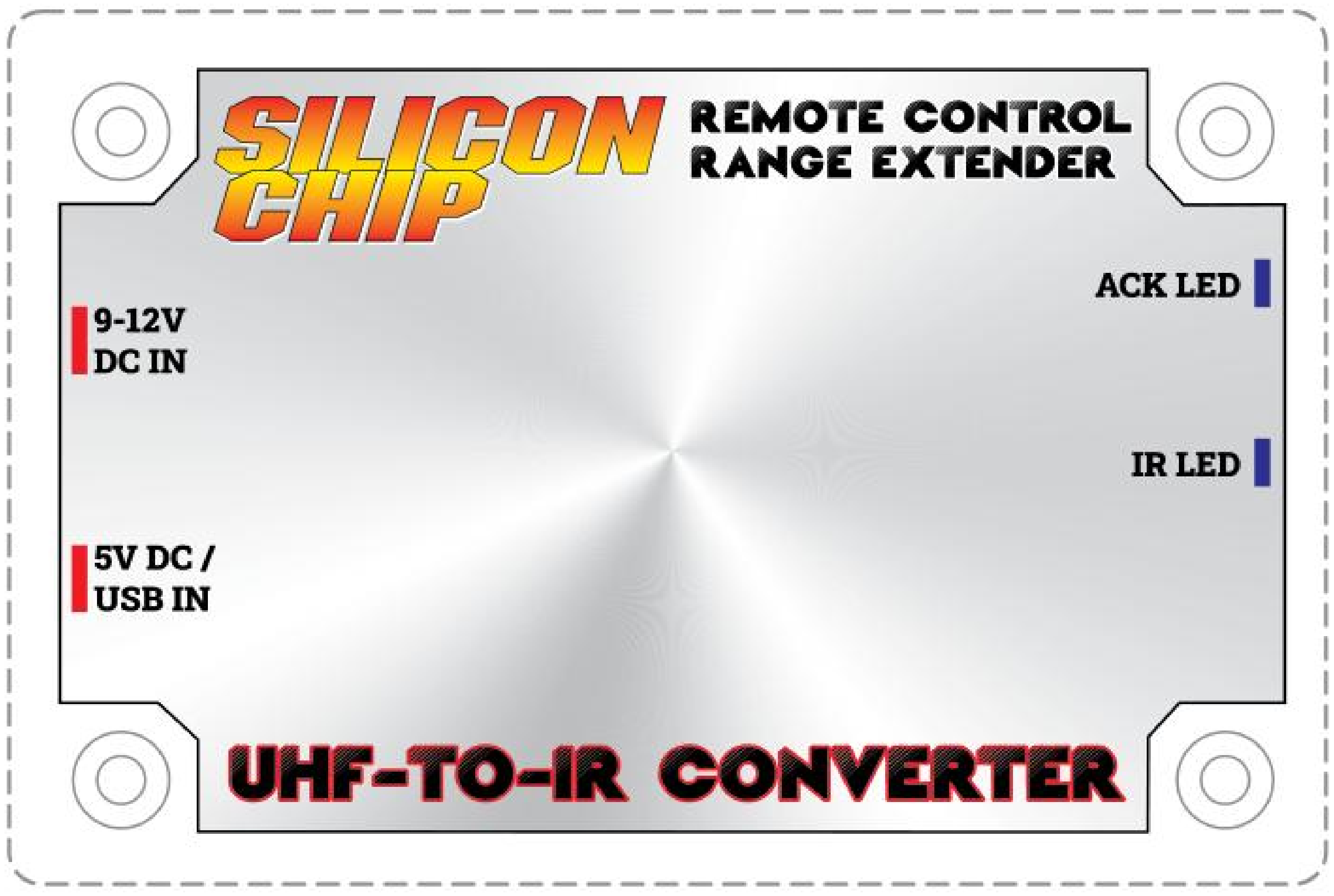
The hole for LED1 can then be drilled 3.5mm down from the lip, directly above the socket hole. Drill this hole to 3mm, then drill a similar hole for LED2 about 12mm to the right. The rectangular USB cut-out can be first drilled and then filed to shape with needle files.

Now clip the PCB into the slots in the side ribs of the box (push the 3.5mm jack socket into its hole first). Once it's in place, bend the two LEDs over and push them through their respective holes in the adjacent end. Secure the assembly by fitting the nut to the jack socket.

The lid label can be downloaded (in PDF format) from the January 2023 page of the *PE* website: (**https://bit.ly/pe-downloads**) printed onto a suitable label and affixed to the lid. The four corner holes for the case screws can be cut out using a sharp hobby knife.

Making an extension cable

Depending on how your gear is arranged, you may want to make up a cable with a 3.5mm jack plug at one end and an external IR LED at the other. Fig.7 shows the details. You will need to use a suitable length of single-core shielded cable, while the LED leads should be insulated from each other using heatshrink tubing.


SILICON CHIP
REMOTE CONTROL
RANGE EXTENDER
ACK LED
9-12V
DC IN
IR LED
5V DC /
USB IN
UHF-TO-IR CONVERTER

The front panel label for the Remote Control Range Extender can be downloaded as a 1-1 scale PDF from the January 2023 page of the PE website: (https://bit.ly/pe-downloads).

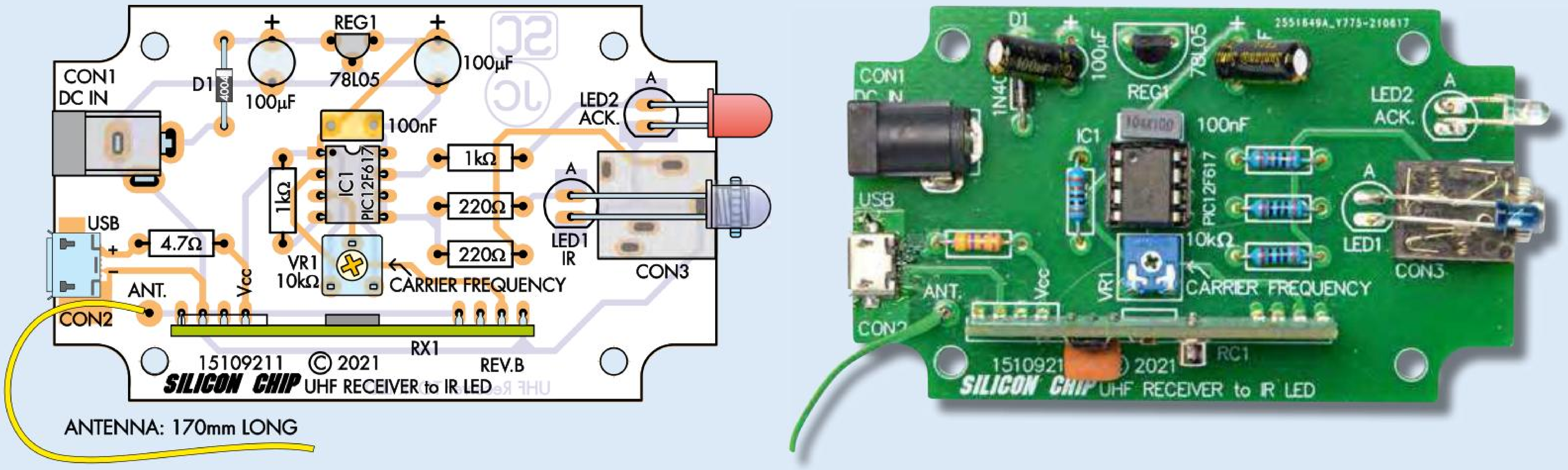

CON1
DC IN
D1
4004
100µF
REG1
78L05
100µF
100nF
LED2
ACK.
A
IC1
PIC12F617
1kΩ
1kΩ
220Ω
220Ω
LED1
IR
USB
4.7Ω
VR1
10kΩ
Vcc
ANT.
CARRIER FREQUENCY
CON3
CON2
RX1
15109211
© 2021
REV.B
SILICON CHIP UHF RECEIVER to IR LED
ANTENNA: 170mm LONG

Fig.5: the assembly of this board is straightforward as the components are much larger than on the other board. Watch the orientations of the UHF receiver, IC1 and diode D1.

Use a length of larger diameter heatshrink tubing to cover the end of the cable, including both LED leads and part of the lens, as shown below.

Testing

First, check that IC1 has not been installed. Apply power and check there is 5V between pins 1 and 8 of the IC socket. If not, verify the supply polarity and ensure that D1 and REG1 are correctly oriented.

If you measure 5V, switch off and install IC1 with its notched end towards the adjacent 100nF capacitor. Now reapply power and check that the red acknowledge LED flashes when the remote control buttons are pressed.

Next, test the appliance. The UHF-to-IR Converter needs to have its IR LED pointing towards the appliance at a range of about 1m. If it doesn't work, adjust VR1 as you operate the remote control until the appliance responds. Usually, setting VR1 mid-way (corresponding to a carrier frequency of around 37kHz) will be suitable.

Once it's operating correctly, try using the remote to control the appliance from another room. You should get a free-air range of 20-25m, but the range will be less than this inside a house, depending on any obstacles (walls, doors, furniture and so on) between the remote and the UHF-to-IR Converter.

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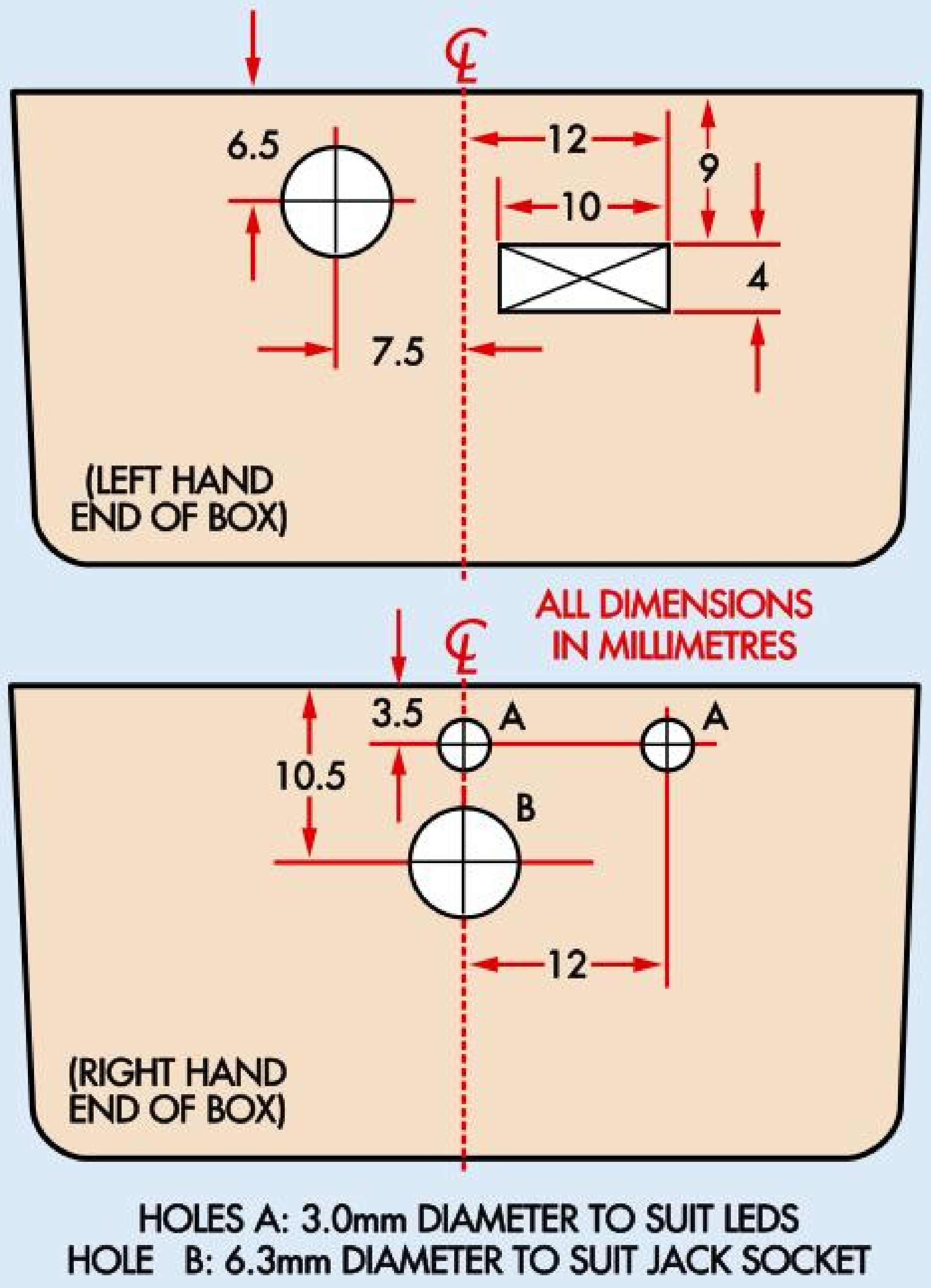
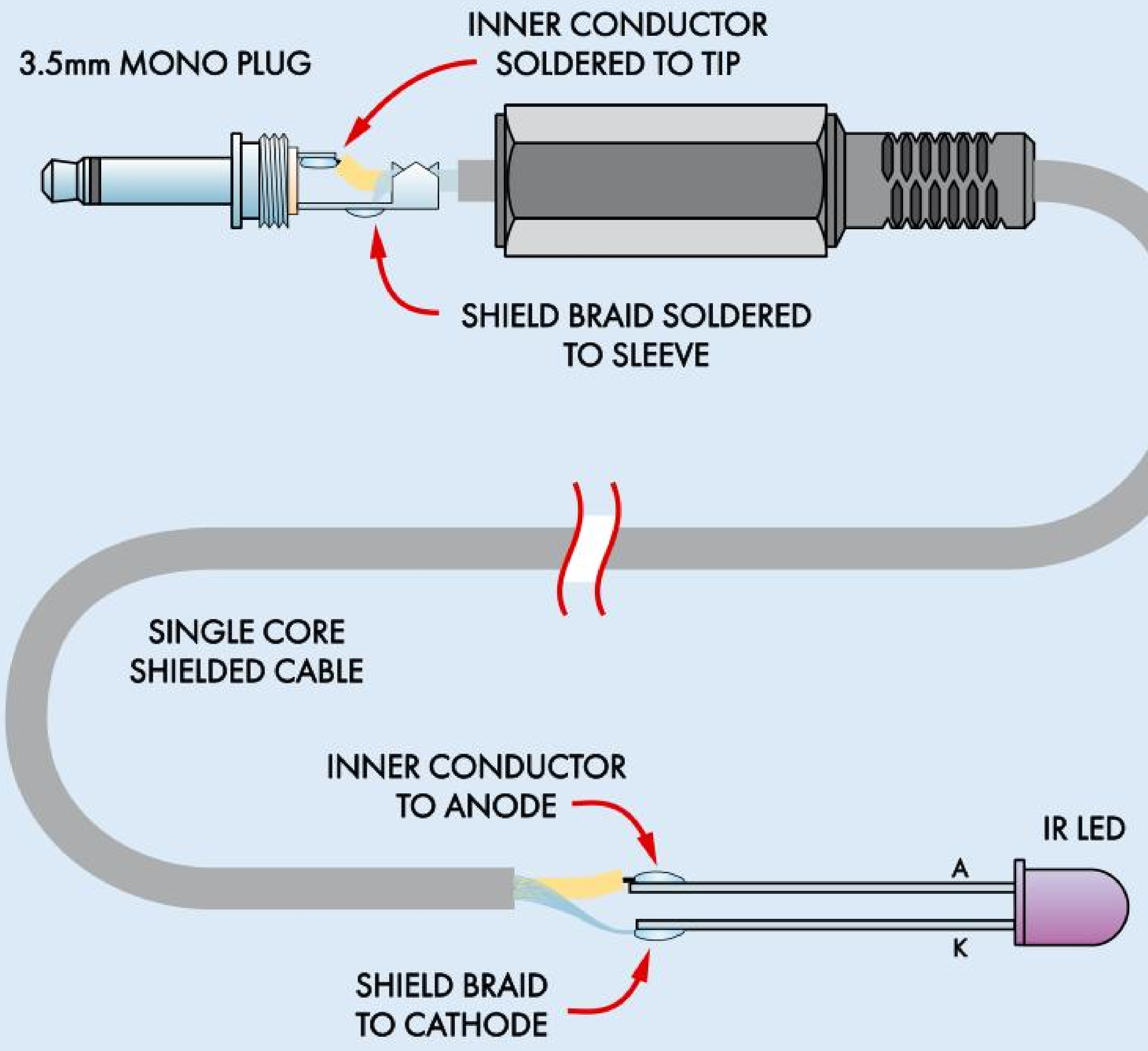
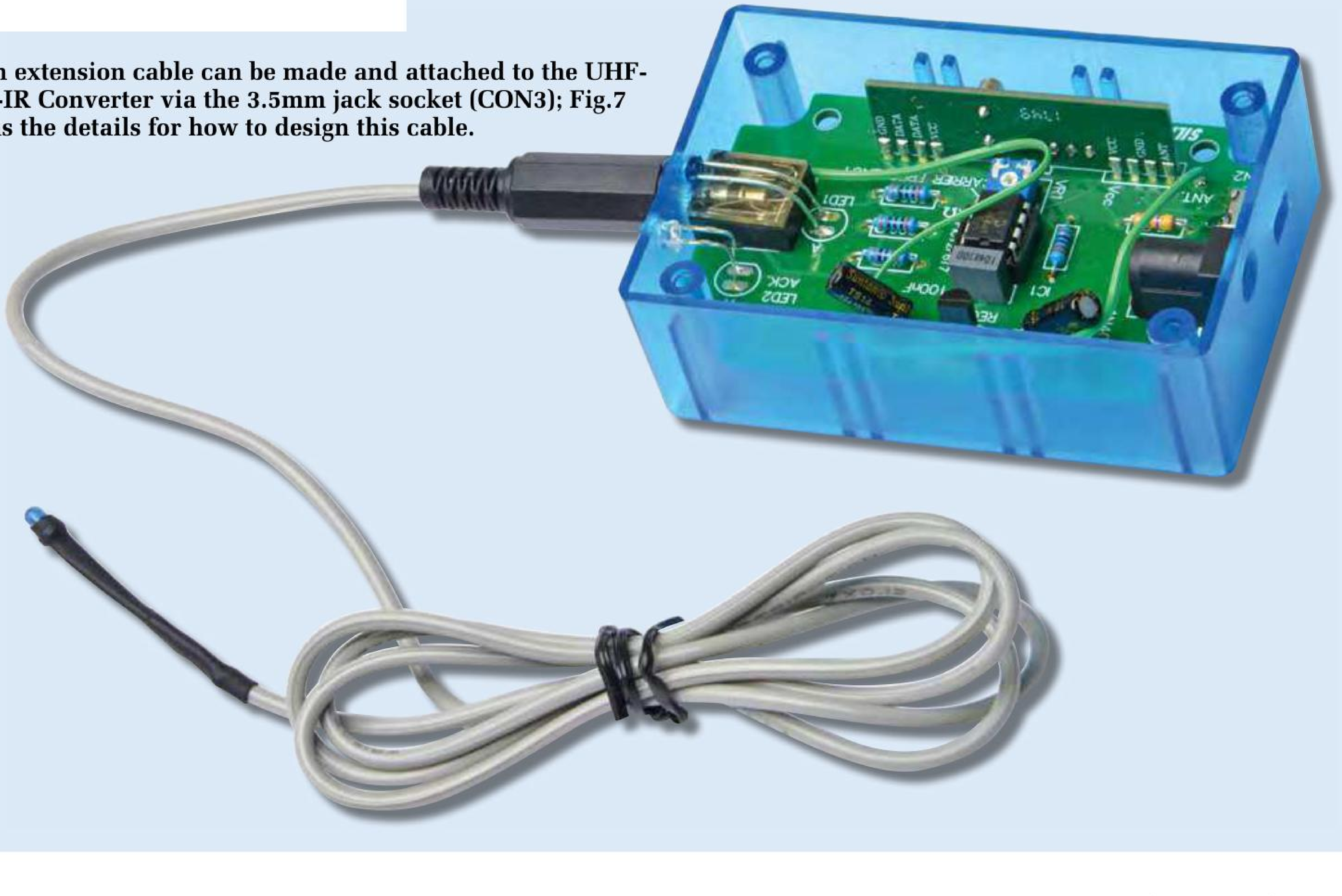

6.5
12
10
9
4
7.5
(LEFT HAND END OF BOX)
ALL DIMENSIONS IN MILLIMETRES
3.5
A
A
10.5
B
12
(RIGHT HAND END OF BOX)
HOLES A: 3.0mm DIAMETER TO SUIT LEDS
HOLE B: 6.3mm DIAMETER TO SUIT JACK SOCKET

Fig.6: shown here are the holes that need to be drilled or cut in the UB5 Jiffy box. The hole for the jack socket in the right-hand end of the box can be left out if you aren't using the IR extension lead, and similarly, you only need to make one hole in the left-hand end, depending on whether you will be using the USB or barrel socket to supply power.

Fig.7: if you need to mount the IR LED away from the receiver unit (eg, mounting it directly in front of the appliance's receiver), you can make up an extension cable as shown here. It plugs directly into the socket on the receiver.


3.5mm MONO PLUG
INNER CONDUCTOR SOLDERED TO TIP
SHIELD BRAID SOLDERED TO SLEEVE
SINGLE CORE SHIELDED CABLE
INNER CONDUCTOR TO ANODE
IR LED
A
K
SHIELD BRAID TO CATHODE

An extension cable can be made and attached to the UHF-to-IR Converter via the 3.5mm jack socket (CON3); Fig.7 has the details for how to design this cable.



- *Protects up to six amplifier modules (six single-ended or three bridged outputs)*
- *Very simple, small in size and low in cost*
- *Can operate from the same power supply as the amplifiers (up to ±40V DC)*
- *Disconnects the speaker(s) in 100ms for full-rail DC fault @ 30V*
- *Provides a 1-2 second turn-on delay, allowing amplifier outputs to settle*
- *Insensitive to low-frequency AC signals*
- *Uses DPDT relays with contacts rated to break 10A @ 28V DC (repetitive)*

Multichannel Speaker Protector
V1.1 2021-09-17
POS GND
25-40VDC
22uF
BC547
47uF

Multi-Channel Speaker Protector

If you're driving a lot of speakers, you will need a matching compact speaker protector to prevent driver destruction, should something go wrong. Our Speaker Protector, when combined with our Hummingbird Amplifier module (published last month), is excellent when driving stereo loudspeakers with an active crossover or for surround sound systems where you have many speakers to drive.

Are your expensive speaker drivers protected if the worst happens, and an amplifier module failure results in them having direct current applied? This very simple and effective board matches our *Hummingbird Amplifier* modules, protecting between one and six channels with a switch-on delay in a PCB measuring just 67 x 120mm for up to six channels, or 67 x 91mm for the four-channel version.

Over a few years of building Hi-Fi and PA equipment, it would be fair to say that this author has not destroyed *that* many speaker drivers. But when I have, it has always been expensive, painful and inconvenient.

The experience of watching a 60W amplifier deliver 40V DC to the voice coil of a very expensive driver that represented months of savings is burnt in my memory. This was a 250W driver but it was no match for 40V DC! In a matter of seconds, the voice coil turned into smoke, much faster than a human being could turn the power off—all for the sake of a 50p insulator.

There have been two main destructors of my drivers:

1. Over-excursion of drivers, particularly in vented enclosures below resonance without appropriate subsonic filtering. This is a surefire way of killing a bass driver.(It can be addressed in active crossovers by including a subsonic filter.)
2. By DC from the output of an amplifier, either due to a failure in the amplifier or finger trouble by the builder. (Have you ever left a fuse out or forgotten to connect a wire?)

This project solves #2. But, you might ask, what about over-powering a speaker? Won't it blow up that way too? In my experience, that takes a heroic effort if your crossover is set up correctly, so we leave the volume control to your discretion.

The impetus

When I built an active crossover combined with six *Hummingbird Amplifier* modules, I found myself running out of room. To fit this lot with power supplies into a 330mm-deep 2RU case, I had to move from beer mat sketches to CAD and 'the computer said' that I needed to make the speaker protector small. So I did.

This device will protect your speaker from most amplifier failures. The modest investment will pay itself off the first time it activates, but we all hope this is one project that you never see 'work'.

By Phil Prosser

There are many ways of approaching a speaker protector. This design aims to keep it simple and small by keeping the parts list to a minimum.

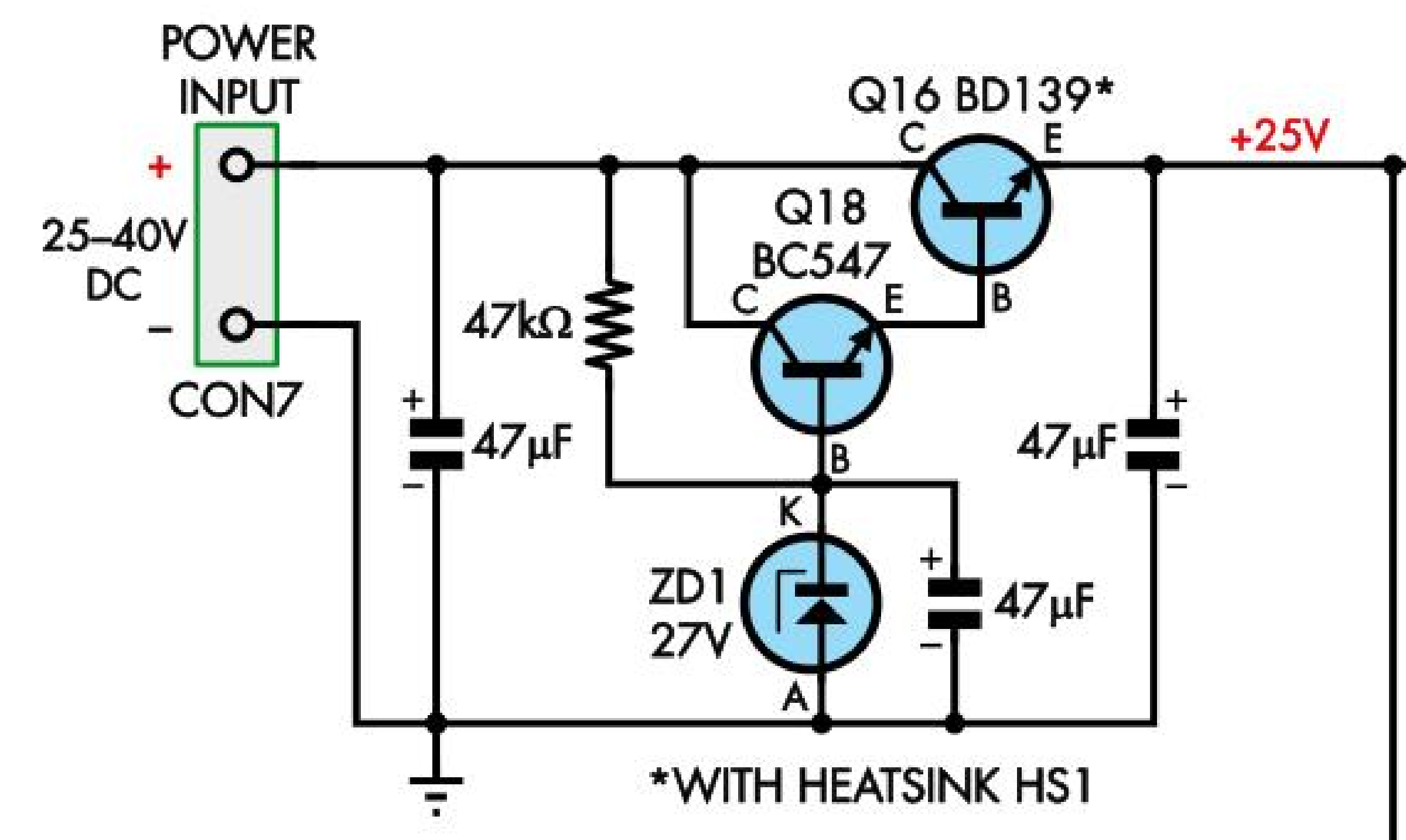
Circuit details

The circuit used is straightforward, as shown in Fig.1, with three duplicated stereo sections providing the six protection channels.

The main part of the *Speaker Protector* circuit is elegant, but it might not be obvious how it works at first glance.

Its first job is to detect the presence of DC at an amplifier output, connected to one of the AMP x OUT terminals at right. This is done by the 100kΩ input resistor and 47µF bipolar capacitor, which form an RC low-pass filter with a –3dB point (corner frequency) of 0.25Hz. The output of this filter feeds a DC detector that triggers at the V_{BE} voltage of a transistor, around 0.6V.

So for regular operation, the amplifier must generate less than 0.6V at the output of this filter. Choosing 10Hz as a 'safe' low frequency limit and assuming an amplifier that can deliver 100W into 4Ω, we can calculate that only 135mV would appear on the output


POWER INPUT
25–40V DC
CON7
Q16 BD139*
Q18 BC547
47kΩ
47µF
ZD1 27V
+25V
*WITH HEATSINK HS1

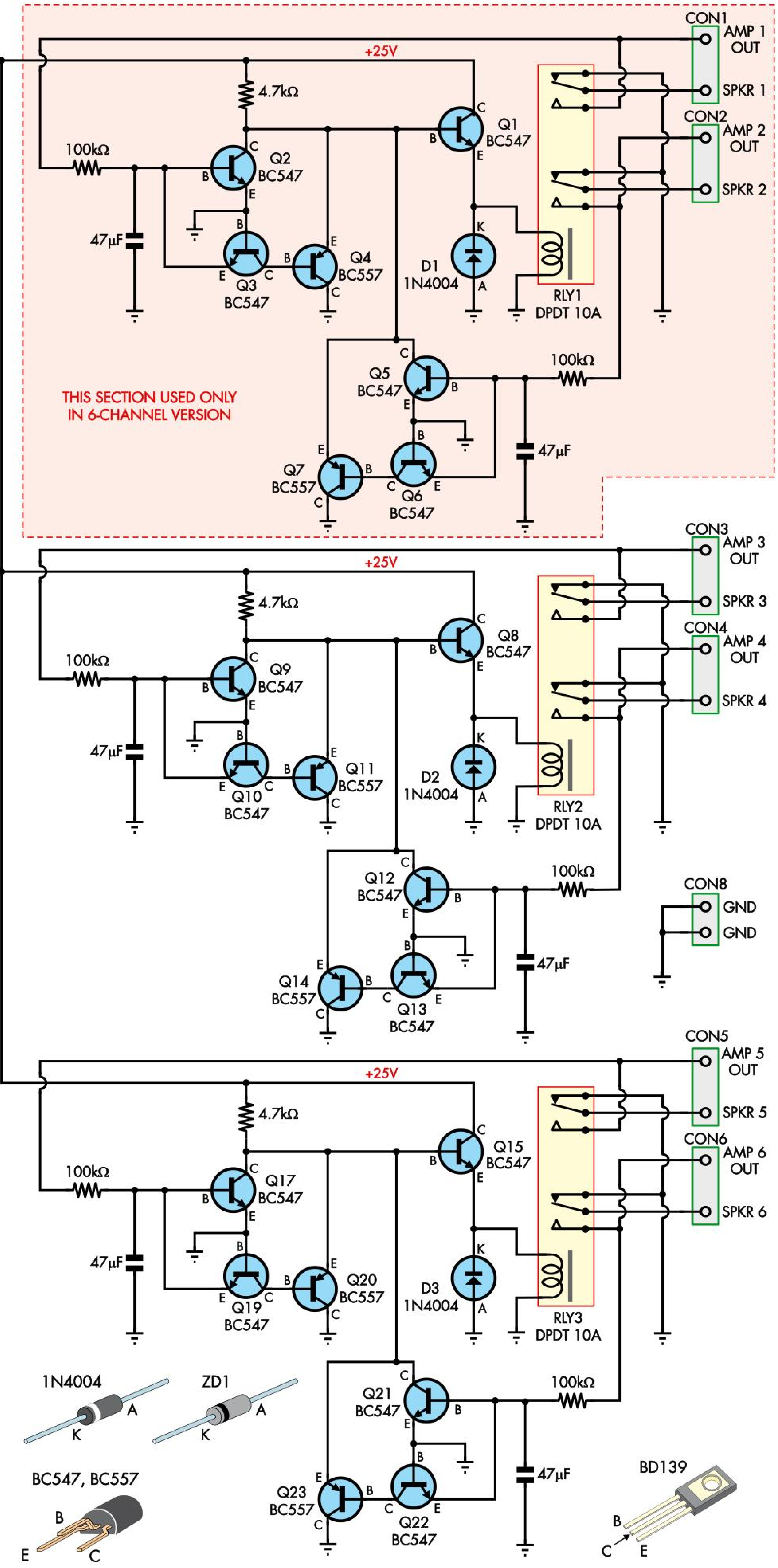

+25V
4.7kΩ
100kΩ
47µF
Q1 BC547
Q2 BC547
Q3 BC547
Q4 BC557
D1 1N4004
RLY1 DPDT 10A
Q5 BC547
Q6 BC547
Q7 BC557
THIS SECTION USED ONLY IN 6-CHANNEL VERSION
CON1 AMP 1 OUT
SPKR 1
CON2 AMP 2 OUT
SPKR 2
Q8 BC547
Q9 BC547
Q10 BC547
Q11 BC557
D2 1N4004
RLY2 DPDT 10A
Q12 BC547
Q13 BC547
Q14 BC557
CON3 AMP 3 OUT
SPKR 3
CON4 AMP 4 OUT
SPKR 4
CON8 GND GND
Q15 BC547
Q17 BC547
Q19 BC547
Q20 BC557
D3 1N4004
RLY3 DPDT 10A
Q21 BC547
Q22 BC547
Q23 BC557
CON5 AMP 5 OUT
SPKR 5
CON6 AMP 6 OUT
SPKR 6
1N4004
ZD1
K A
BC547, BC557
B E C
BD139
B C E

Fig.1: the Speaker Protector has three identical sub-circuits handling two channels each. Each input signal passes through a simple RC low-pass filter and is applied to three transistors. If a large DC voltage is detected, those transistors switch off the associated DPDT relay, disconnecting the speaker from the amplifier. A basic linear power supply provides around 24V to drive the relay coils and incorporates a switch-on delay of around one second to avoid thumps.

of the filter. So it won't trigger during regular amplifier use.

But say an amplifier goes faulty and delivers its rail voltage of 40V DC (of either polarity) to the output instead of an AC waveform. In that case, after 100ms (0.1s), the low-pass filter output will reach 0.84V, which will definitely trigger the DC detection circuit that follows. This filter operates identically for both positive and negative voltages.

With 40V across 8Ω for 100ms, 20J of energy will be delivered to the voice coil (the impedance will drop over time, approaching its DC resistance value, but this is a good enough approximation). This will make a solid thump and probably make you jump, but it won't cause anything to catch on fire. Even better, if the fault exists from switch-on, the speaker will simply never be connected.

The DC Detector comprises a total of three transistors. For the top-most section in Fig.1, these are Q2, Q3 and Q4. Positive DC detection is handled by Q2, which has its collector tied directly to the 4.7kΩ load resistor. A positive voltage from the filter of more than about 0.6V will switch this transistor on and consequently pull the base of Q1, an emitter follower, low and thus turn off the relay.

Q3 and Q4 detect negative voltages. NPN transistor Q3 is connected in a common-base configuration; its base is tied to ground, and its emitter is the input. A negative input voltage will pull current from 0V via the base-emitter junction, causing its collector to sink current. Because the current it sinks at the collector goes to the emitter, this current must be kept low.

Hence, this tiny current is buffered by Q4, a PNP device connected as an emitter-follower. The emitter of Q4 connects to the same resistor as the collector of Q1. So a negative DC voltage from the filter similarly pulls the base of Q1 low, switching the relay off.

There is a balance in this circuit between setting a low cut-off frequency and the minimum DC voltage

Parts List – Multi-Channel Speaker Protector

1 double-sided plated-through PCB coded 01101221, 67 x 121.5mm available from the *PE PCB Service*
3 (2) 30V DC 10A contact, 24V DC coil DPDT PCB-mount/cradle relays (RLY1-RLY3) **[Altronics S4313, Jaycar SY4007]**
8 (6) 2-way 5.08mm pitch mini terminal blocks (CON1-CON8)
1 44mm-tall, 16.5 x 10mm PCB-mount finned heatsink (HS1; for Q16) **[Altronics H0645]**
1 TO-126 or TO-220 silicone insulating washer and insulating bush **[Altronics H7230, Jaycar HP1176]**
1 M3 x 10mm panhead machine screw
1 M3 shakeproof washer
1 M3 hex nut
4 tapped spacers and 8 machine screws (to suit installation)

Semiconductors
16 (11) BC547B/C 50V 100mA NPN transistors, TO-92 (Q1-Q3, Q5, Q6, Q8-Q10, Q12, Q13, Q15, Q17-Q19, Q21, Q22)
6 (4) BC557B/C 50V 100mA PNP transistors, TO-92 **[BC558-9B/C will also work]** (Q4, Q7, Q11, Q14, Q20, Q23)
1 BD139 80V 1.5A NPN transistor, TO-126 (Q16)
1 27V 1W zener diode (ZD1) **[1N4750]**
3 (2) 1N4004 400V 1A diodes (D1-D3)

Capacitors
6 (4) 47µF bipolar/non-polarised electrolytic **[Jaycar RY6820]**
3 47µF 50V electrolytic **[Altronics R4807 or Jaycar RE6344]**

Resistors *(all 1/4W 1% metal film axial)*
6 (4) 33k-100kΩ (see text; if unsure, use 100kΩ)
1 47kΩ
3 (2) 4.7kΩ
(n) *for the four-channel version (PCB code 01101222, 67 x 91mm), the quantities required are listed in red.*

at which the circuit will switch the relay off. 47µF is a reasonable maximum for the filter capacitor, so any tweaking is best done by varying the value of the input resistor(s).

We chose the 100kΩ value to guarantee no problems with false triggering for very high power, very low frequency applications. But if you are not protecting a subwoofer, any value greater than 33kΩ should be fine and, as a bonus, lower values will provide faster turn-off for fault conditions.

The 100kΩ resistors also affect the lowest DC voltage that will cause the detector to trigger. A fault in the amplifier front-end could cause a few volts DC to be present at the output, and if applied to a driver for long enough, it could overheat and be damaged. So ideally, we want to detect that condition too, not just a fault where it immediately pegs to one of the supply rails.

Assuming a minimum transistor h_{FE} of 120, and that the relay will switch off with 20V across the 4.7kΩ resistor (leaving just a few volts across the relay coil), the transistor base current must be at least (20V ÷ 4.7kΩ) ÷ 120 = 35µA (or thereabouts) to switch the relay off. This means the DC from the amplifier must be at least 3.5V (35µA x 100kΩ) to trip the relay off.

But this is with a worst-case h_{FE} value. We recommend using BC547B or BC547C transistors, which have higher guaranteed h_{FE} figures and will switch the relay off with about 1.5V DC on the input. Lowering the input resistors would reduce that trip voltage further.

The *DC Speaker Protector* disconnects the speaker any time that DC is detected. The relays used are robust and should be able to interrupt the fault current that can be expected from a *Hummingbird Amplifier* module or similar. However, there is the possibility that upon disconnection, the voltage and current will be high enough to form an arc between the relay contacts.

The normally closed contact of the relay is used to shunt this current to ground when the speaker is disconnected. So if an arc forms and current continues to flow, the amplifier's DC fuse for that rail will blow, and the arc will extinguish. You likely have a failed output transistor already, so a blown fuse won't exactly be high on your list of concerns.

We have put three sets of this circuitry on one board, allowing six standard amplifier channels to be monitored and protected. The relay selected has a standard pinout and is available from many suppliers. Make sure that you get the correct version, though; we are specifying 24V DC coils, though you could use 12V provided you adjust the DC regulator, and the BD139 can handle its heat load (see below).

The circuit uses the power ground pin as the ground reference. This connects to the earth of the power amplifiers being protected. Since the inputs are already paired up, this *Protector* would work well for DC protection in a bridged amplifier.

The power supply

The power supply is a basic series-pass regulator generating about 25V DC. The relays need 24V on their coils, and this suits amplifiers with various rail voltages. It can be adapted for supplies below ±25V or above ±40V (see below).

The power supply provides a turn-on delay of about one second. This is because the 47kΩ resistor delays the charging of the 47µF capacitor at the base of Q18. This applies to all channels protected by the board. As you increase the supply voltage, the turn-on delay decreases slightly because the capacitor will charge faster. You could compensate for that by increasing the resistor value if needed.

If you have an amplifier with rails below ±25V, you have the option of swapping the relays for 12V DC coil versions and make necessary adjustments in the regulator (we expect a 15V zener would work well for ZD4). Similarly, if you have higher rail voltages, this should be fine; just watch the sizing of the heatsink. The specified Altronics H0655 heatsink (or similar) should be fine for any normal rail voltage.

Construction

Construction is straightforward. There are two PCBs available; a six-channel version (coded 01101221, 67 x 120mm) and a four-channel version (coded 01101222, 67 x 91mm), both available from the *PE PCB Service.*

We have described the six-channel version here; the four-channel version is identical except that one relay and its associated components are omitted, so the PCB is smaller. Refer to the appropriate overlay diagram, Fig.2 or Fig.3, during assembly.

Start with the resistors and diodes. Make sure you get the diodes in the right way around. Then mount the two-way terminals for power, each input/output pair and the earth terminal to prevent any arcing in the relays (CON8).

Now it's time to solder in the BC5XX transistors. Try to mount them at the same height so it looks neat.

Next come the capacitors. The three 47µF polarised capacitors need to be rated at 50V DC, and all go in the same way, with the longer positive leads to the pads marked +. The six 47µF bipolar/non-polarised electrolytic capacitors do not need a high voltage rating as they will never see more than 0.6V – they mount to the PCB in any orientation.

Now fit the BD139 to the heatsink using an insulating washer, 10mm M3 machine screw, locking washer and nut. Solder the heatsink to the PCB, but remember it can be hard to get enough heat into it to solder those big pins.

Finally, mount the relays. The PCB has 1.5mm holes which are the minimum that this family of relay recommends – the devices from Altronics and Jaycar leave a fair bit of room in the holes. Solder them in well.

Testing

Now that you have all the parts mounted, it is time to test it out. During the initial tests, leave the amplifier terminals (CON1-CON6) disconnected.

First apply power and check for the 25V output of the regulator The end of the closest 4.7kΩ resistor right near Q11 is a convenient place to probe; you can use the anode of any of diodes D1-D3 as a ground reference. The reading should be between 24V and 26V for an input above 32V DC.

If this is not present or correct, check that ZD4 has about 27V across it; if not, look to the 47kΩ resistor and transistors Q16 and Q18. Check that these two transistors are the right types and soldered in correctly. Also check for short circuits – is the BD139 getting hot?

After a second or two, the relays ought to click in. If this does not happen, check the voltage on the bases of Q1, Q8 and Q15 (the driver transistors for the relays). Are these within a volt or two of the 25V rail? If not, check that they are the proper devices and soldered in correctly.

Check the voltage at the output of the RC filters. The voltage at both ends of the 100kΩ resistors (or other value you might have changed them to) should be close to 0V. If not, check that the BC547 and BC557 parts are in the right places and they are oriented correctly.

Assuming the relays do switch on, let's check that they trip off correctly.

The easiest way to test it is to take a 9V battery and connect the negative end of the battery to the ground terminal on the DC protector. Then touch a wire from the positive pin of the battery to the 'AMP' terminal of each installed channel of the DC protector. The associated relay should switch out almost instantly.

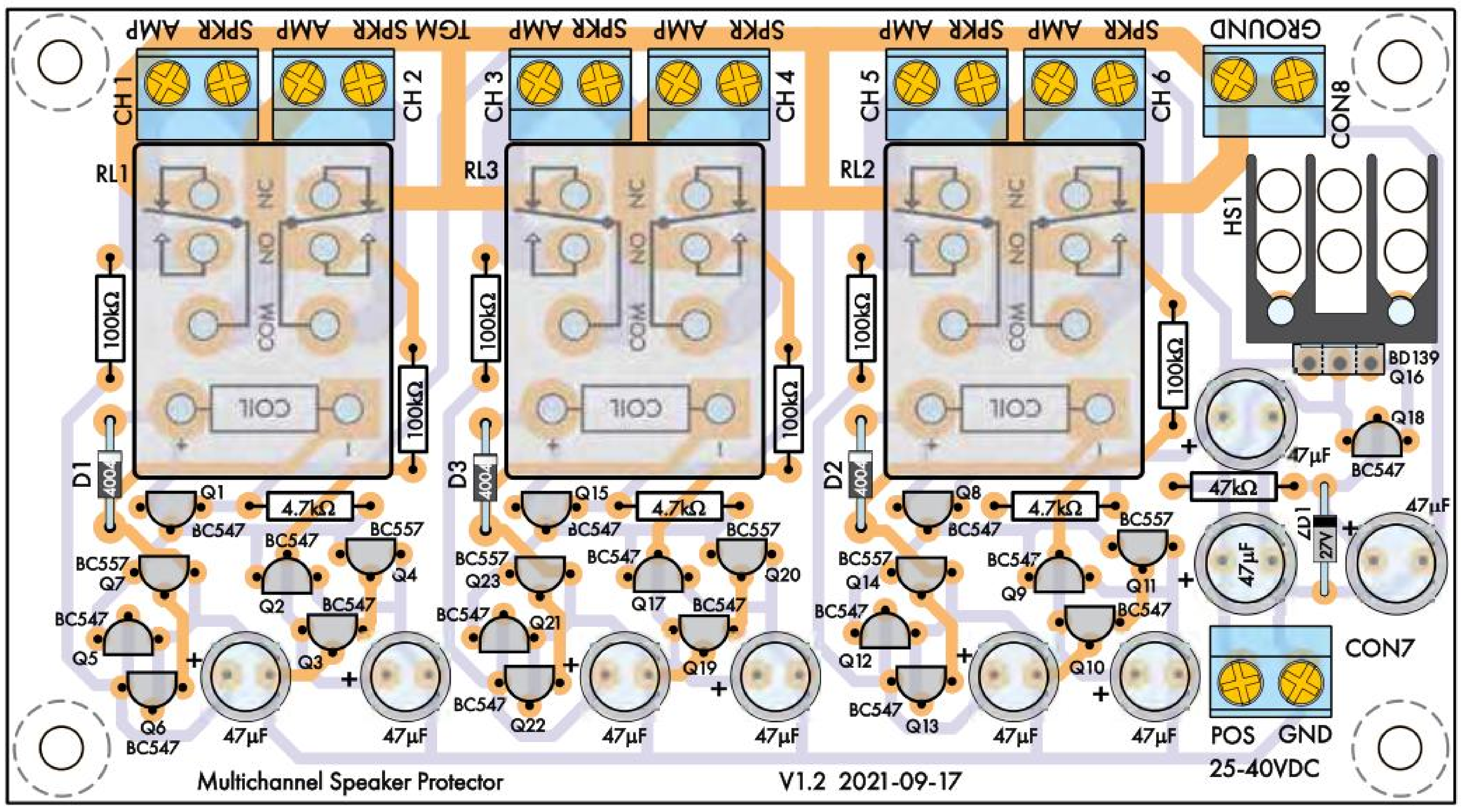
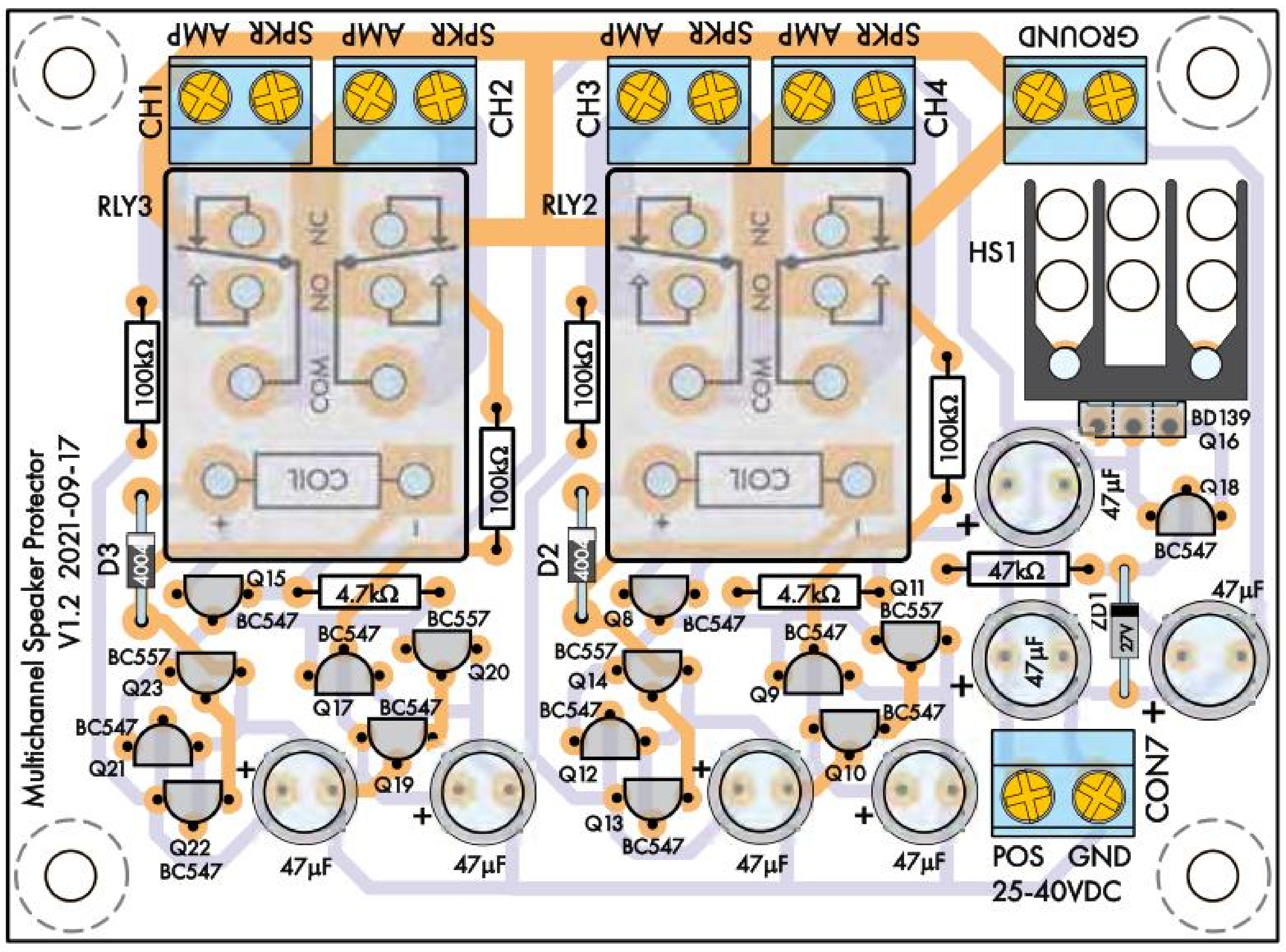
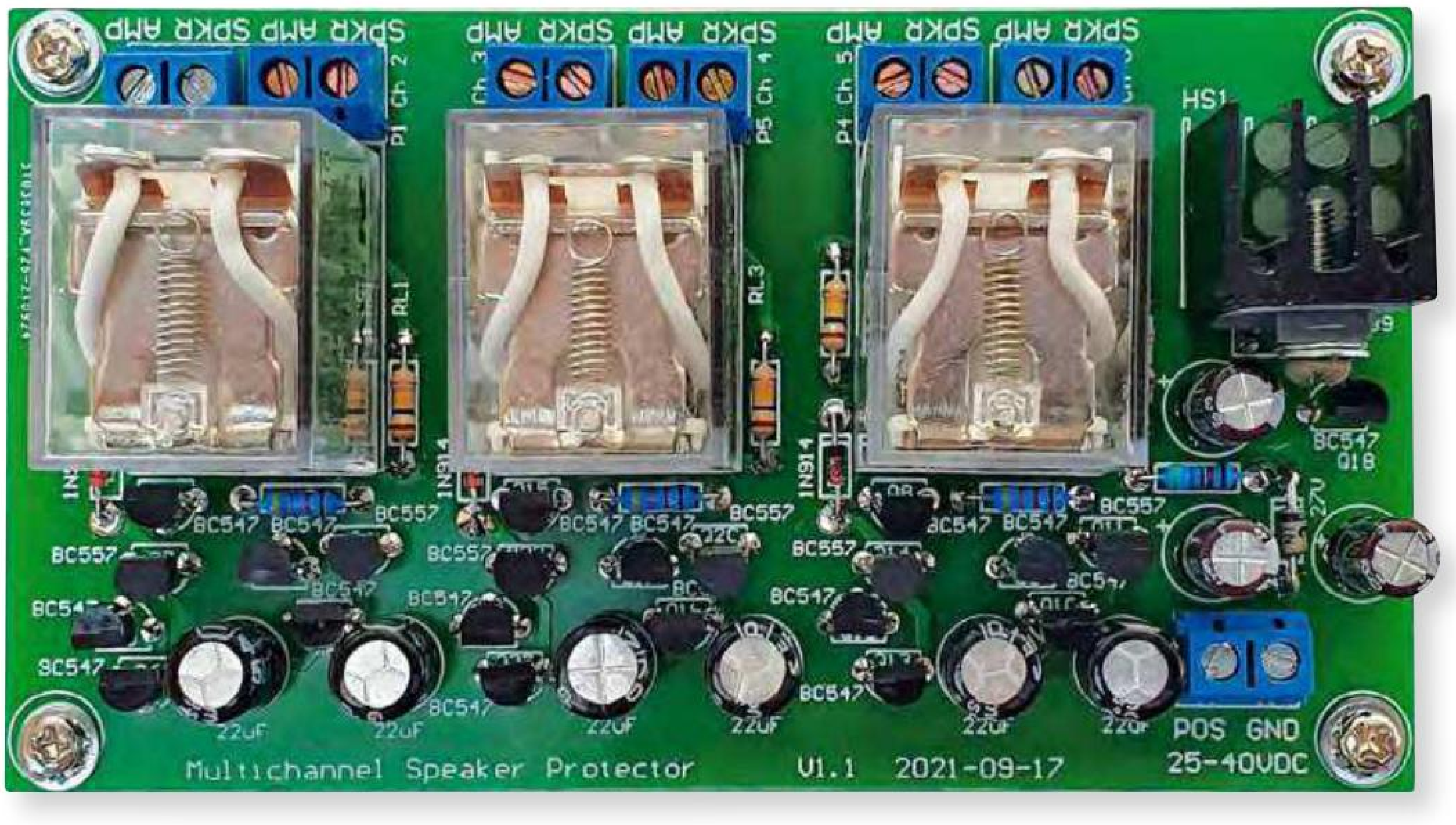

SPKR AMP
SPKR AMP
TGM SPKR AMP
SPKR AMP
SPKR AMP
SPKR AMP
GROUND
CH 1
CH 2
CH 3
CH 4
CH 5
CH 6
CON8
RL1
RL3
RL2
HS1
NC
NO
COM
COIL
100kΩ
D1
D3
D2
4.7kΩ
47kΩ
ZD1
27V
BD139
Q16
Q18
BC547
BC557
Q1
Q2
Q3
Q4
Q5
Q6
Q7
Q8
Q9
Q10
Q11
Q12
Q13
Q14
Q15
Q17
Q19
Q20
Q21
Q22
Q23
47µF
CON7
POS GND
25-40VDC
Multichannel Speaker Protector
V1.2 2021-09-17

Fig.2 and Fig.3: build the smaller board to protect up to four channels, or the slightly larger board for five or six channels. Assembly is straightforward; all components are through-hole types and can be fitted in order from shortest to tallest (the latter being the relays and heatsink for Q16).


SPKR AMP
SPKR AMP
SPKR AMP
SPKR AMP
GROUND
CH1
CH2
CH3
CH4
RLY3
RLY2
HS1
NC
NO
COM
COIL
100kΩ
D3
D2
4.7kΩ
47kΩ
ZD1
27V
BD139
Q16
Q18
BC547
BC557
Q8
Q9
Q10
Q11
Q12
Q13
Q14
Q15
Q17
Q19
Q20
Q21
Q22
Q23
47µF
CON7
POS GND
25-40VDC
Multichannel Speaker Protector
V1.2 2021-09-17

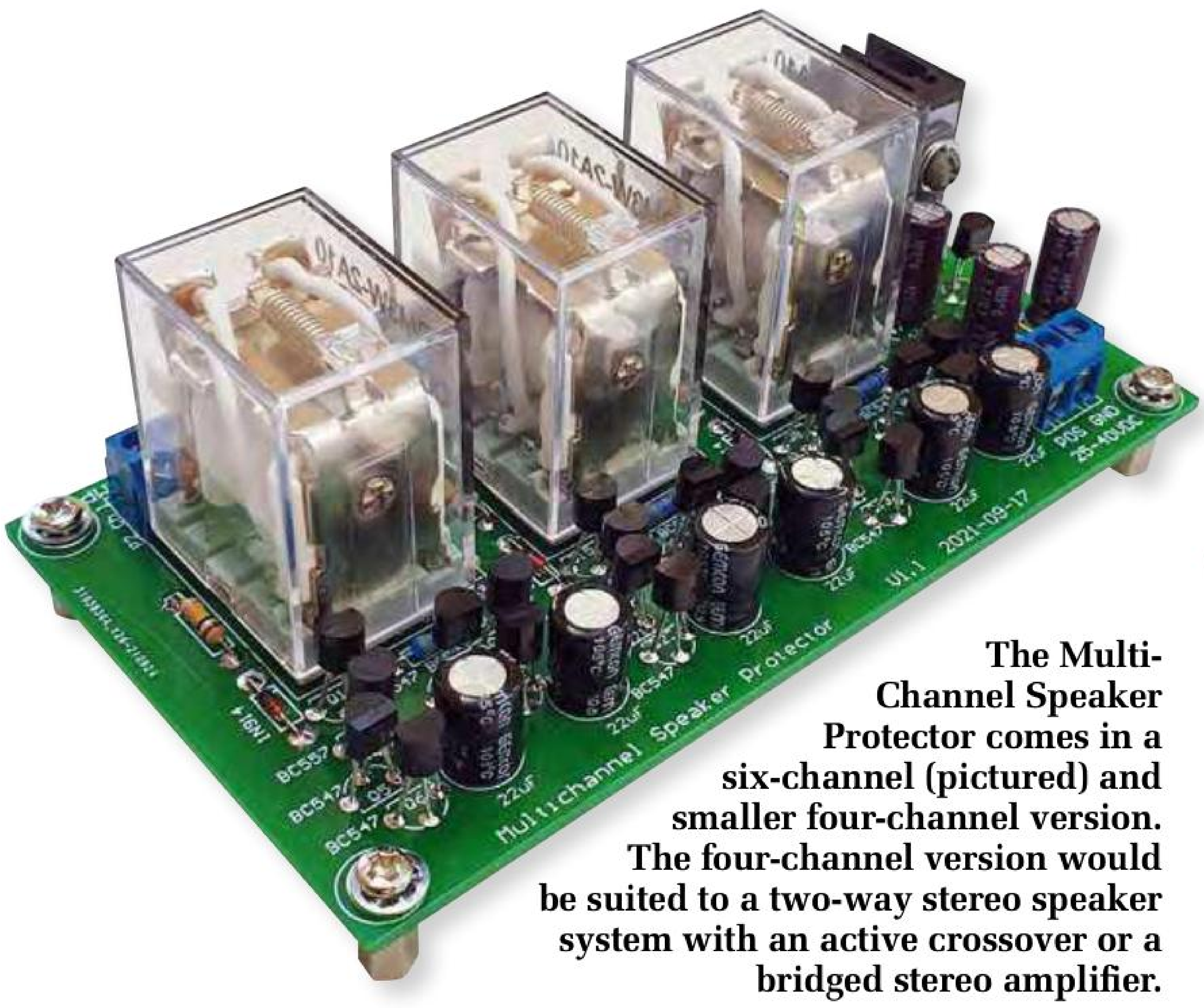

SPKR AMP SPKR AMP
SPKR AMP SPKR AMP
SPKR AMP SPKR AMP
HS1
BC547
Q18
POS GND
25-40VDC
Multichannel Speaker Protector
V1.1 2021-09-17

The finished Speaker Protector board will look something like this. Note the holes drilled into the board under the heatsink to allow convection to pull fresh air up from underneath. The CON8 (GROUND) terminal block is missing on this prototype version; you could leave it off, but it provides better protection for the speakers if you wire it up to the amplifier earth.

Repeat this for all channels, checking that the relays switch quickly. Then repeat the test with the battery the other way around (ie, positive terminal to GND and negative to the AMP terminals).

If a channel does not switch as expected, measure the voltage at both ends of the 100kΩ resistor. One should be ±9V, the other ±0.6V.

If the ±9V end is not correct, there is a short or open circuit somewhere in that area. If the other end is not close to +0.6V, check the two NPN



The Multi-Channel Speaker Protector comes in a six-channel (pictured) and smaller four-channel version. The four-channel version would be suited to a two-way stereo speaker system with an active crossover or a bridged stereo amplifier.

Remember to fit an insulating washer to the BD139 transistor (visible above) to prevent it from shorting out on the heatsink. Also note the use of shakeproof washers on all screws so they won't loosen due to vibration or movement.

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transistors on the DC detector (eg, Q9 and Q10), especially their orientations. Check the associated PNP transistor (eg, Q11) for a fault where you aren't registering –0.6V.

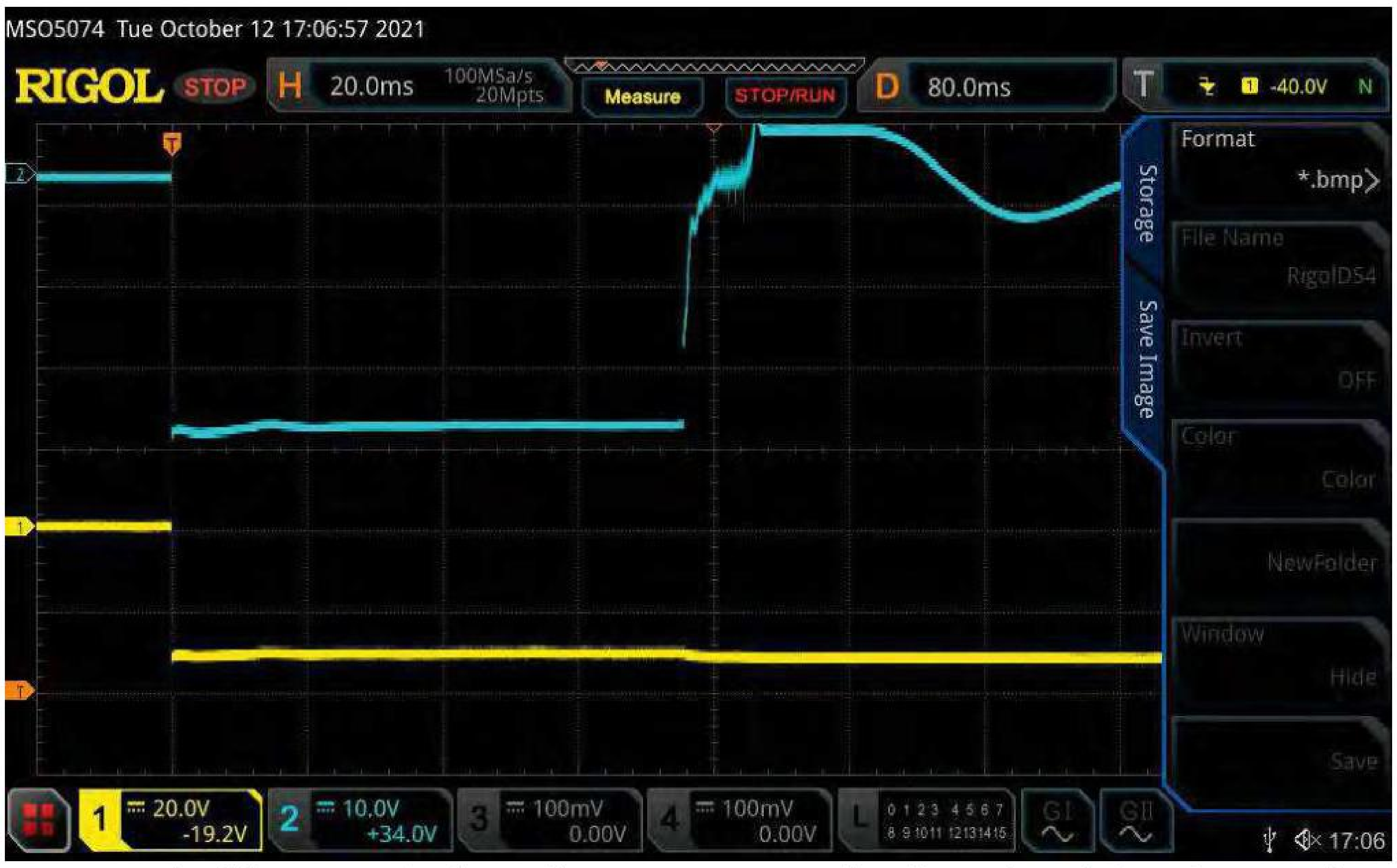
We don't suggest you do this, but to verify that the *Protector* does indeed protect the driver, we connected a 4Ω subwoofer to the *DC Speaker Protector* along with a 6A limited, –34V power supply to the 'AMP' input of the *Protector*. There was a solid thump and click as the relay saved the sub from inevitable destruction. We monitored this with an oscilloscope, and the result is shown in Scope 1.

We noted a flash of arcing as the speaker was disconnected, which is no surprise when breaking the very high direct current flow. Please don't try this at home, as a speaker protector does not make this sort of thing safe for your speaker.

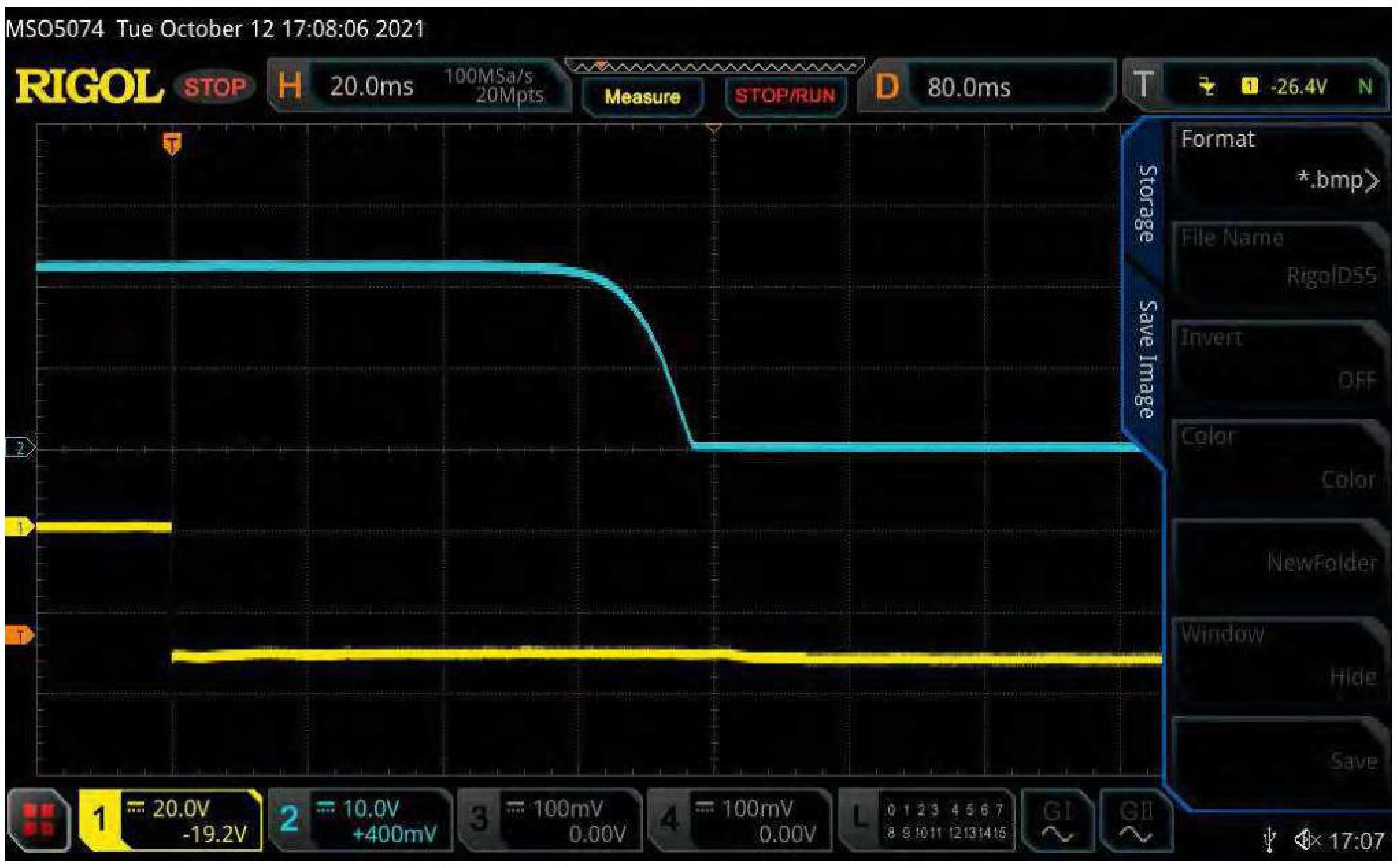
Application

The *DC Speaker Protector* needs to be connected to the power amplifier ground/earth via the provided terminal (CON8) and supplied with 30-40V DC to the power connection (CON7). If your amplifier has a higher positive rail voltage than this, you can use a 5W wirewound resistor to drop the supply voltage to the *Protector*. The six-channel *Protector* draws about 100mA, so a 100Ω 5W resistor will drop 10V and dissipate about a watt.

Connect the terminals marked AMP to the amplifier and the corresponding SPKR terminal to your speaker outputs. It's OK to leave some channels unused; for example, if you have a 3- or 5-channel amplifier. Once installed in your amplifier, let's hope that you never hear those relays click unexpectedly. But if you do, you will be glad they are there!


MSO5074 Tue October 12 17:06:57 2021
RIGOL
STOP
H 20.0ms
100MSa/s
20Mpts
Measure
STOP/RUN
D 80.0ms
T
-40.0V
N
Format
*.bmp
Storage
File Name
RigolDS4
Save Image
Invert
OFF
Color
Color
NewFolder
Window
Hide
Save
1 20.0V -19.2V
2 10.0V +34.0V
3 100mV 0.00V
4 100mV 0.00V
17:06

Scope 1: the blue trace is the voltage across a 4Ω loudspeaker driver (zero volts at top), while the yellow trace is –34V applied to the DC Speaker Protector from a bench supply. The speaker is disconnected in less than 80ms. The AC voltage generated by the cone movement due to back-EMF after the relay disconnected the driver will not occur in this final version as long as CON8 is connected to earth, as that will brake the cone movement.


MSO5074 Tue October 12 17:08:06 2021
RIGOL
STOP
H 20.0ms
100MSa/s
20Mpts
Measure
STOP/RUN
D 80.0ms
T
-26.4V
N
Format
*.bmp
Storage
File Name
RigolDS5
Save Image
Invert
OFF
Color
Color
NewFolder
Window
Hide
Save
1 20.0V -19.2V
2 10.0V +400mV
3 100mV 0.00V
4 100mV 0.00V
17:07

Scope 2: this scope grab shows the response time of the Protector to a 20V DC fault. The input voltage step is at t=0 and the output starts to drop before t=60ms. It reaches 0V before t=80ms. The 80ms delay is due to the RC time constant of the filter reaching 0.6V.

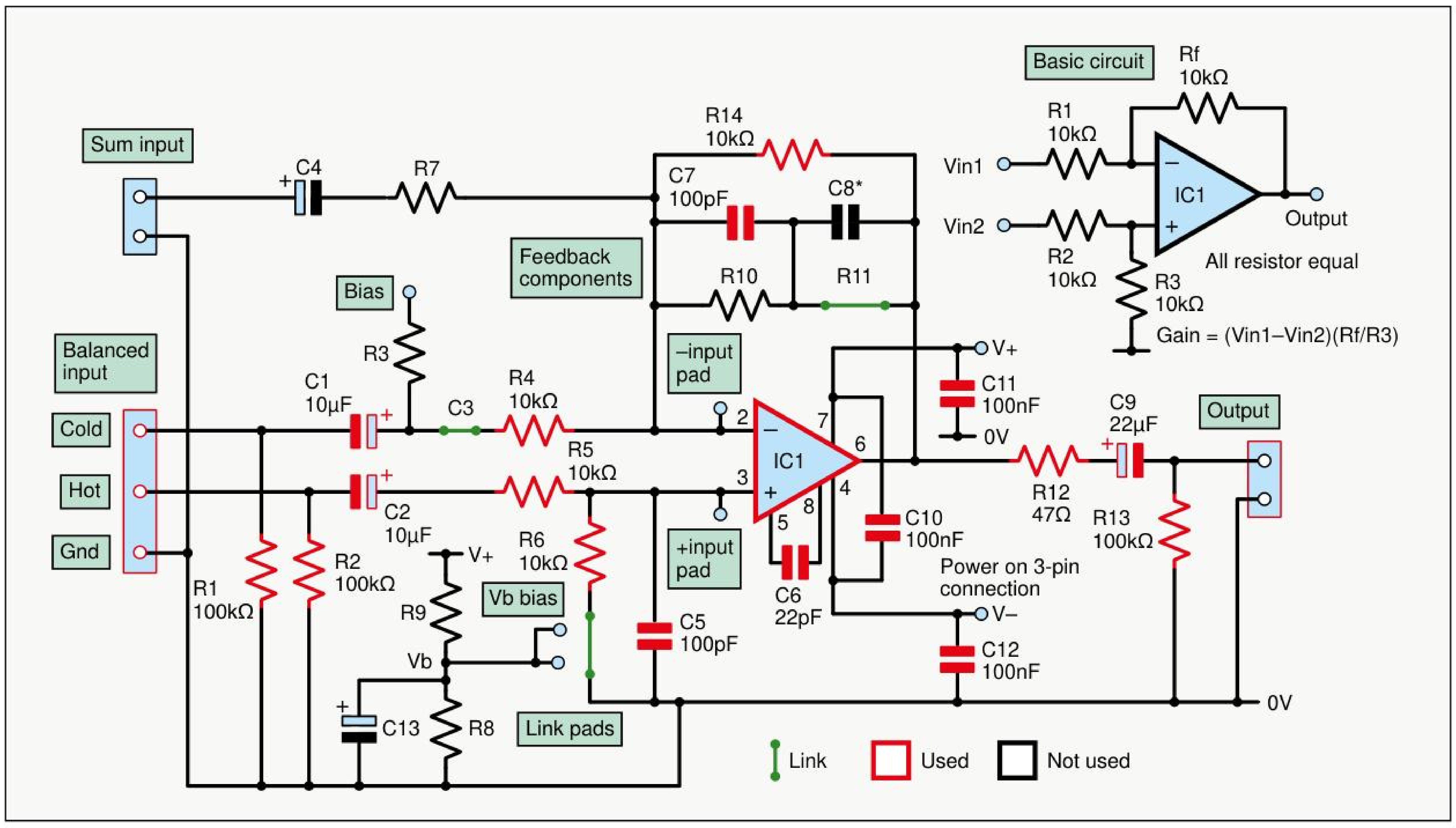
AUDIO OUT

By Jake Rothman

Universal single op amp board (optimised for audio electronics) – Part 2

Fig.18. Differential or balanced input amplifier, possibly the most common add-on op amp circuit for converting consumer audio equipment to professional operation.

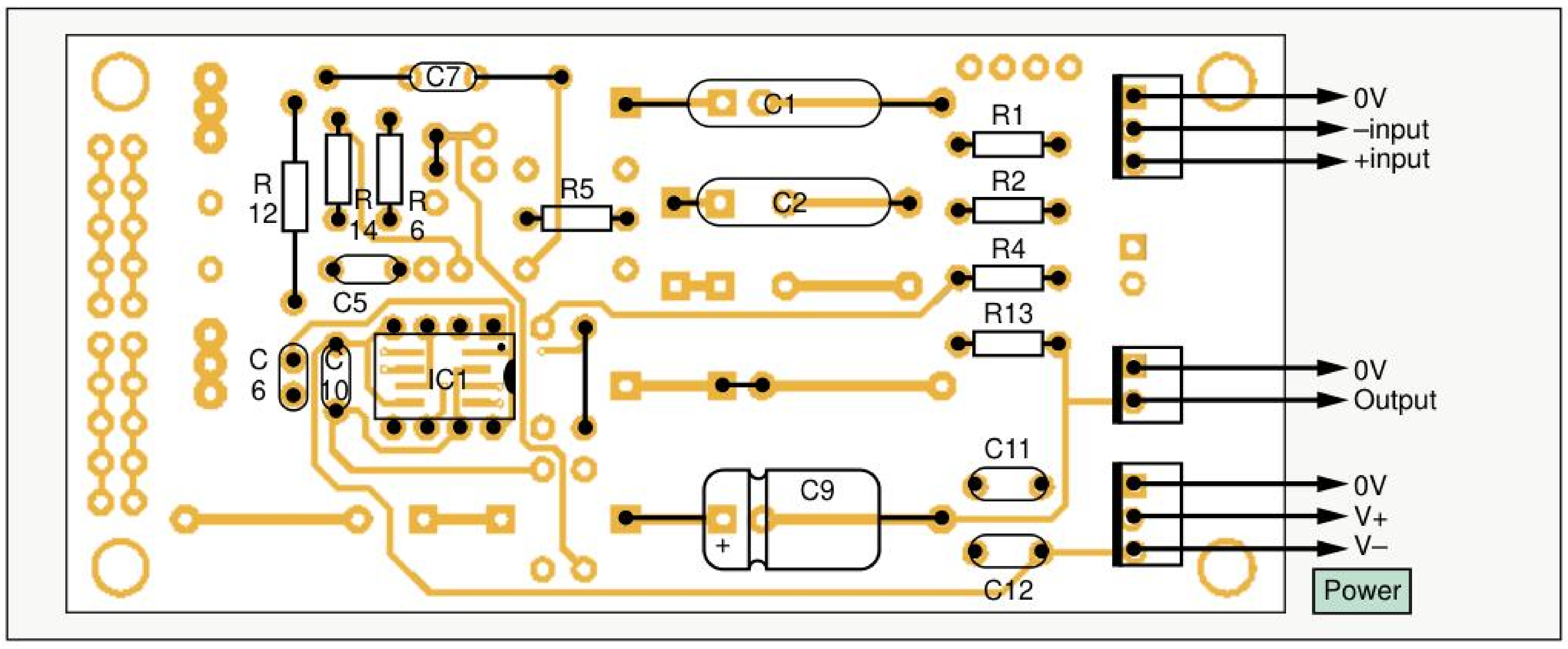
Remember that for each amplifier shown, only the red components and green links are used.


Basic circuit
Rf 10kΩ
R1 10kΩ
Vin1
Vin2
R2 10kΩ
IC1
Output
All resistor equal
R3 10kΩ
Gain = (Vin1–Vin2)(Rf/R3)
Sum input
C4
R7
R14 10kΩ
C7 100pF
C8*
Feedback components
R10
R11
Bias
R3
Balanced input
Cold
Hot
Gnd
C1 10µF
C3
R4 10kΩ
R5 10kΩ
–input pad
+input pad
2
3
7
6
4
5
8
IC1
V+
C11 100nF
0V
C9 22µF
Output
R12 47Ω
R13 100kΩ
C2 10µF
V+
R6 10kΩ
Vb bias
R1 100kΩ
R2 100kΩ
R9
Vb
C13
R8
Link pads
C5 100pF
C6 22pF
C10 100nF
Power on 3-pin connection
V–
C12 100nF
0V
Link
Used
Not used

Last month, we introduced our *Universal Single Op Amp Board*, a really useful op amp-based amplifier PCB that is perfect for both design/development and finished products. It takes a through-hole or SMD op amp, around which you have lots of options for adding passive components so that you can build a whole host of common amplifier configurations.

I'm an audio engineer, so it's not surprising that I've designed the board with audio in mind, but there is absolutely no reason why it can't be used for instrumentation or any other high-quality op amp application that requires a quick and easy PCB solution.

We've already covered the op amp non-inverting, inverting and summing amplifier configurations, and this month we will look at three more handy designs.


C7
C1
R1
0V
–input
+input
R 12
R 14
R 6
R5
C2
R2
R4
C5
R13
C 6
C 10
IC1
0V
Output
C11
C9
0V
V+
V–
C12
Power

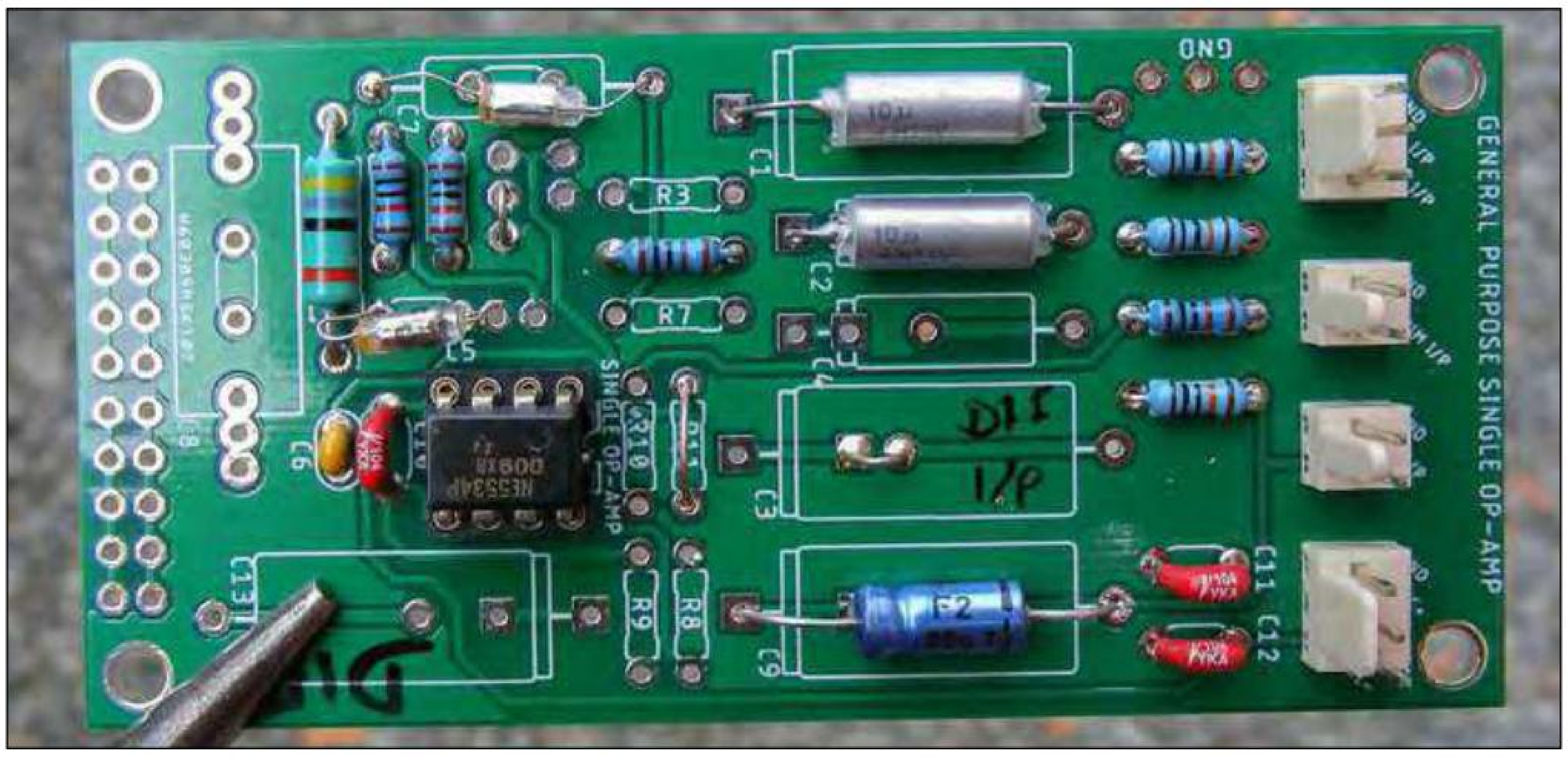

GENERAL PURPOSE SINGLE OP-AMP
NE5534P
DIF I/P
DIF

Fig.19. (right middle) Component placement for differential amplifier.
Fig.20. (right) The finished differential amplifier board.

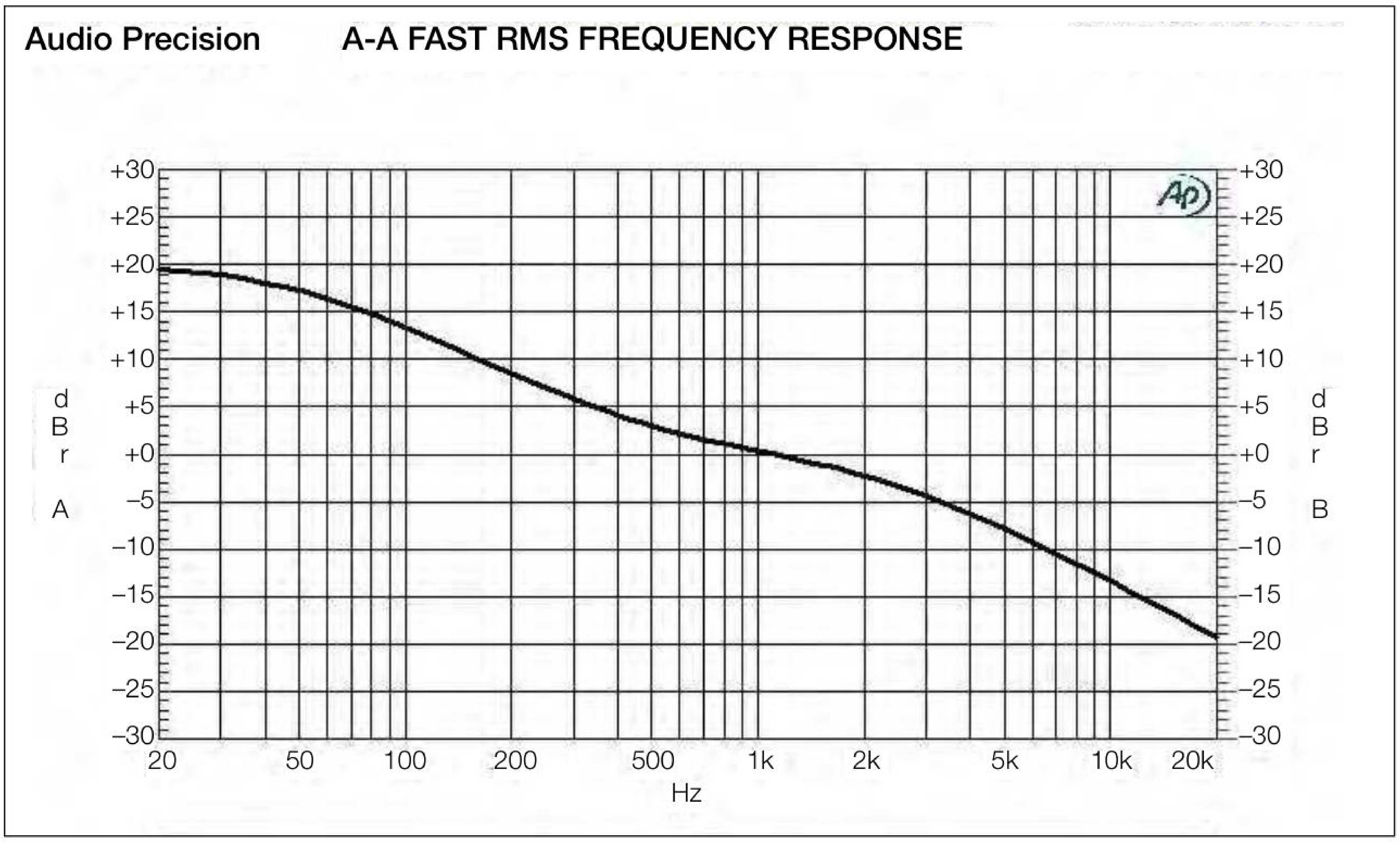


Fig.21.Measured RIAA curve of the phono amplifier circuit in Fig.22. Mid-band gain at 1kHz is +30dB. Max gain is +50dB at 20Hz giving 150mV for a typical cartridge input of 5mV at 1kHz. This requires a lot of open-loop gain for a single op amp; however, this approach generally gives the best noise and overload capability if all the gain and equalisation is done in one first stage.

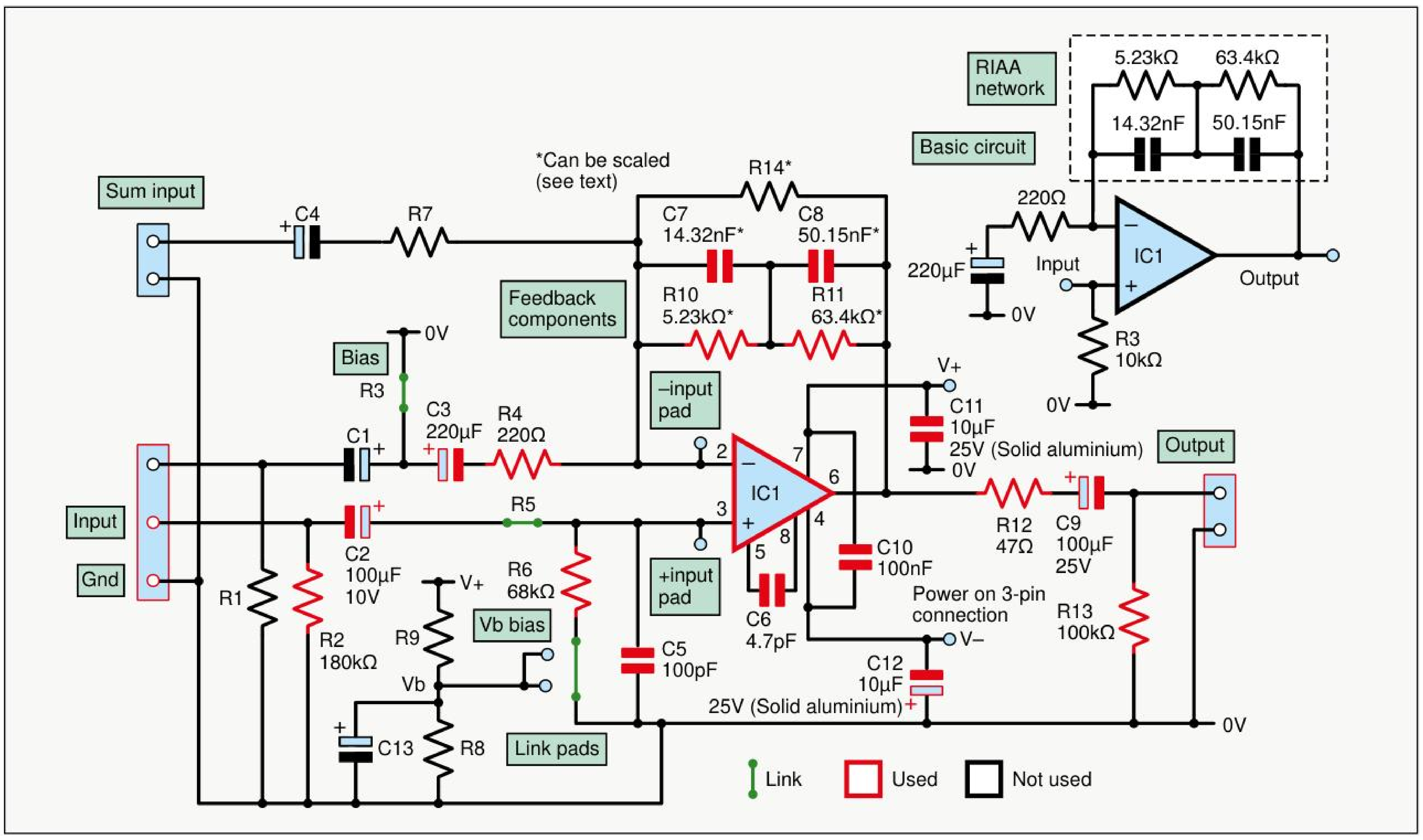

RIAA network
5.23kΩ
63.4kΩ
14.32nF
50.15nF
Basic circuit
220Ω
220µF
Input
0V
IC1
Output
R3 10kΩ
*Can be scaled (see text)
R14*
Sum input
C4
R7
C7 14.32nF*
C8 50.15nF*
Feedback components
R10 5.23kΩ*
R11 63.4kΩ*
Bias
0V
R3
–input pad
V+
C11 10µF 25V (Solid aluminium)
0V
C1
C3 220µF
R4 220Ω
Output
Input
R5
IC1
R12 47Ω
C9 100µF 25V
Gnd
C2 100µF 10V
R6 68kΩ
V+
+input pad
C10 100nF
R1
R2 180kΩ
R9
Vb bias
C6 4.7pF
Power on 3-pin connection
V–
R13 100kΩ
C5 100pF
C12 10µF
25V (Solid aluminium)
Vb
C13
R8
Link pads
0V
Link
Used
Not used

Fig.22. Phono amplifier circuit – if you are using only one op amp (as here) to accomplish the RIAA equalisation, then odd RC values are needed for the negative feedback network.

Differential amplifier

This amplifier is useful for adding a balanced input to consumer audio equipment. The input is connected via the three-pin Molex. C3 is normally replaced with a wire link (short). As with the non-inverting amplifier, R6 can be linked to the bias point for single-rail operation. The circuit is shown in Fig.18, the overlay in Fig.19 and the final stuffed board in Fig.20.

Now we've covered the basic amplifiers, here's a couple of more specialised circuits that can be built on the board.

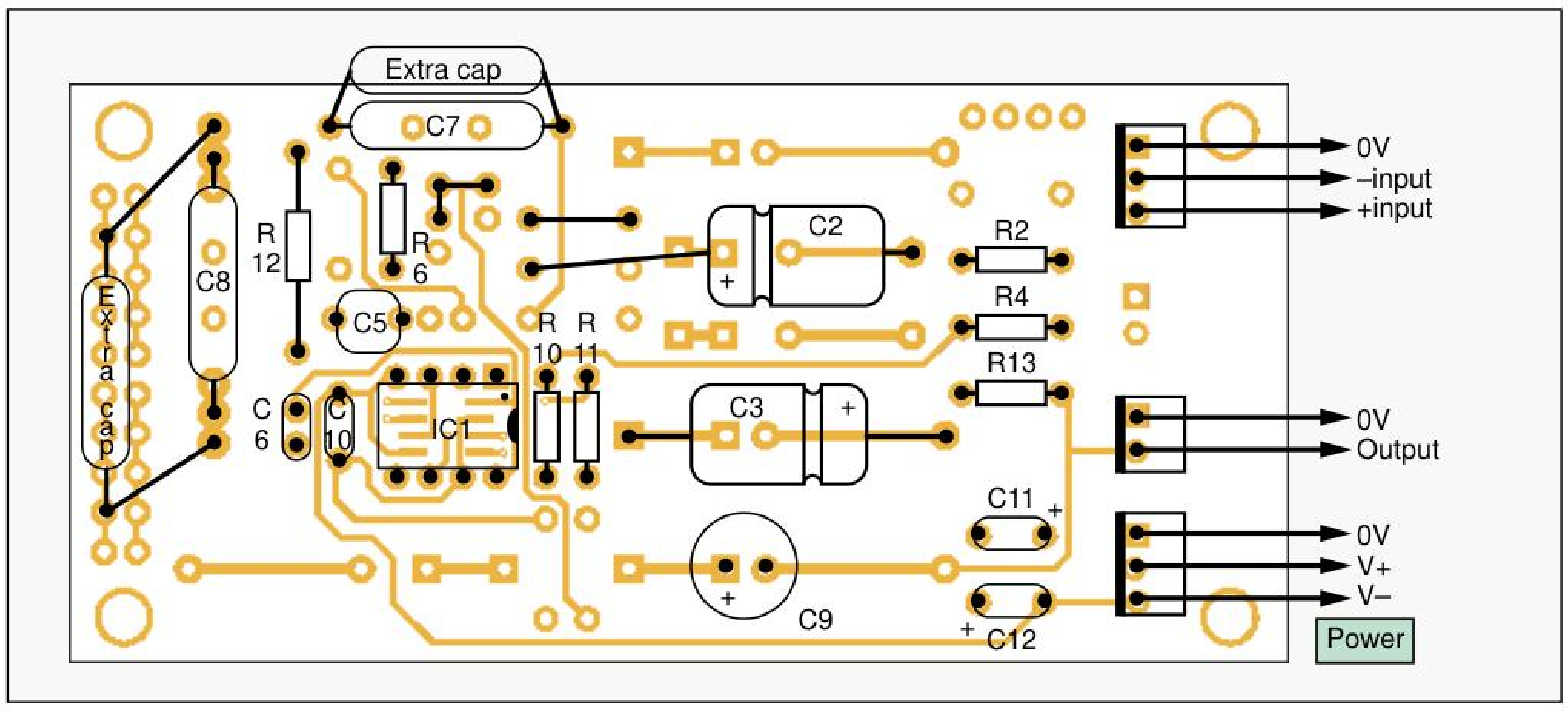

Extra cap
C7
Extra cap
C8
R 12
R 6
C5
R 10
R 11
C 6
C 10
IC1
C2
R2
R4
R13
C3
C11
C9
C12
0V
–input
+input
0V
Output
0V
V+
V–
Power

Fig.23. Component placement for phono amplifier. Note extra capacitors wired in parallel.

RIAA phono amplifier

This is probably the most complex design to be built on this board. The equalisation to implement the RIAA curve, shown in Fig.21, requires non-standard-value components with a tolerance of 2% or better. These values are difficult to calculate, but Douglas Self has got them all worked out in his book *Electronics for Vinyl*. Getting the E96 resistors is not too difficult now, and Farnell's pricing is reasonable with their Vishay 1% MRS25 series

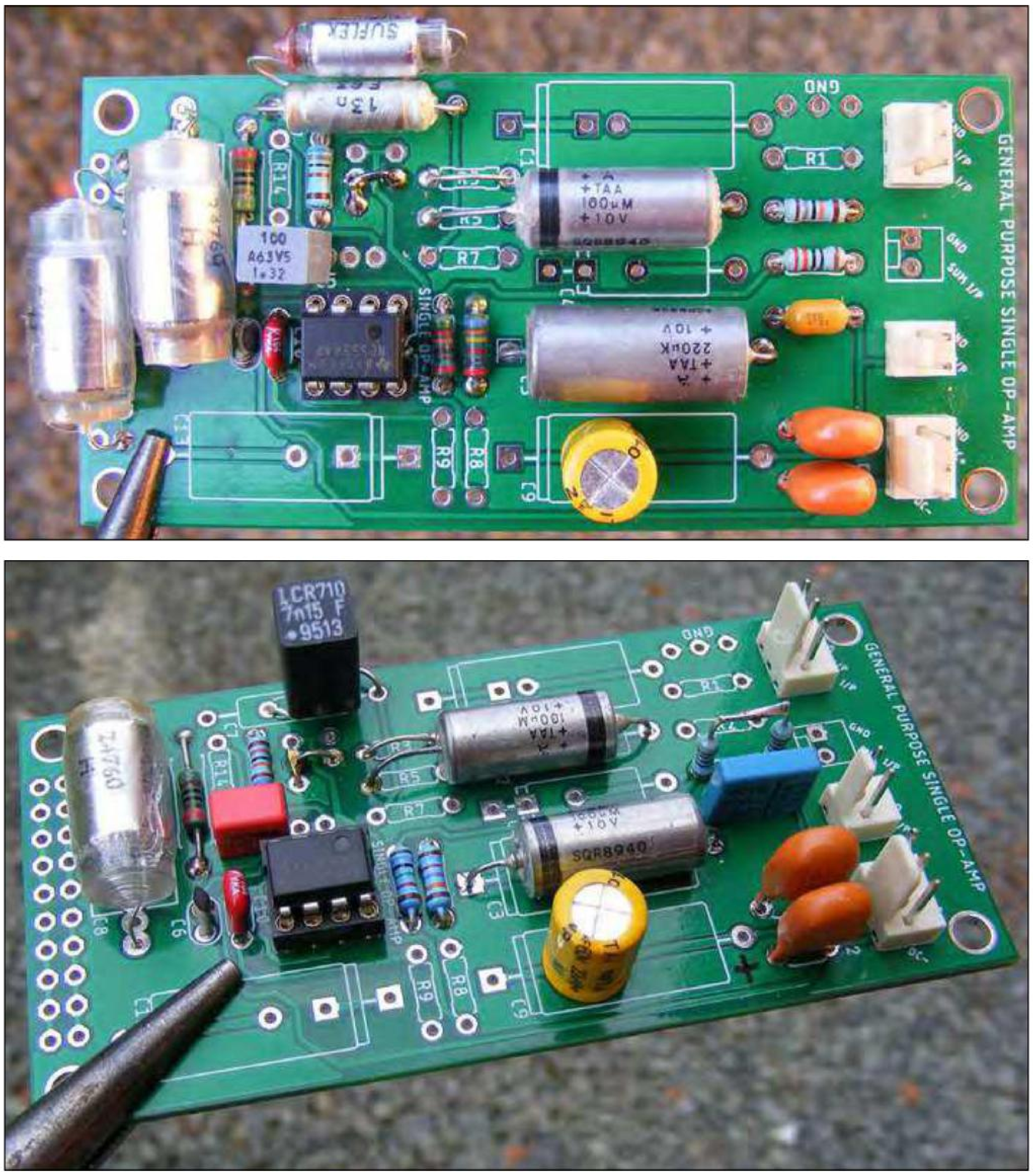


Fig.24. (above) Phono amplifier construction – a bit untidy, but it can at least be accommodated on the board; (below) Alternative RIAA amplifier construction. Single capacitors are used for C7 and C8, but half the value. Resistors R10, R11 and R4 are scaled up to 10.5kΩ, 127kΩ and 442Ω respectively.

if you buy a lifetime's supply of 100! Mouser are cheaper, supplying the 1% Yeago MFR-25FBF52 series. (Often, E96 resistors are 0.1% and can cost a fortune, so these 1% options are well worth considering).

Getting accurate capacitors is more difficult and ±1% or 2.5% tolerance devices are considered top-notch, but here in Wales, home of the UK's 'capacitor cluster', LCR (who absorbed Suflex) still make excellent polystyrene capacitors, available from the author – see contact details in the AO Shop ad on p.50.

To aid constructors I've made available some low-cost kits of these odd-value resistors and capacitors (also via the AO Shop). The 50.15nF capacitor (C8) can be made up using two surplus Suflex 1% 24.76nF capacitors in parallel (giving 49.52nF) using the extra pads as shown earlier in Fig.6. You can add an extra 680pF as well for more precision. The other capacitor (C7) needs to be 14.32nF and I made mine out of a parallel 13nF and 1.3nF. I rescued these caps out of a skip at the end of a production run of filters and they are all still spot-on. Of course, five 10nF capacitors, or any other combination could be used for C8.

These were the original Doug Self values. For a simpler version (Fig.24, lower), I decided to double the resistor values and halve the capacitors, so only two capacitors, one of the 24.76nF and an LCR 7.15nF were needed. The noise increases by about 1dB by doing this because of the higher impedance. To provide the final part of the RIAA curve, –20dB at 20kHz relative to 1kHz, a further low-pass filter is required. This is due to the op amp's response flattening off to unity, since the non-inverting configuration has a minimum gain of one. This is achieved with a 4.7nF capacitor inserted in R13's position in conjunction with a higher-than-normal value for R12 (510Ω). This network should be omitted if a roll-off at 66kHz is provided further on, as is usually the case, such as with stabilising capacitors or an output balancing transformer. The compensation capacitor (C6) is 4.7pF, which works in practice, even though the gain of the circuit falls to unity at high frequencies. The theoretical value should be 22pF, but the lowest high-frequency distortion is achieved with lower values. The coupling capacitors can all be tantalum. There is no distortion problem since the signal levels are all below 1V$_{pk\text{-}pk}$. The polarity of the capacitors is unimportant for dual rail, although fusspots may wish to align them with the offsets.

For bipolar op amps with high input bias currents feeding NPN input transistors, such as the NE5534, the output offset is usually negative. Therefore, the negative terminal of the electrolytic capacitors should be connected to the op amp. The circuit is shown in Fig.22 and the overlay in Fig.23, along with the final construction in Fig.24a and b. The NE5534 is still one of the best op amps for moving magnet cartridges and the NE5534A version has guaranteed noise specs. I've only got significantly better than this by using ±25V discrete circuits with an expensive J74 JFET on the front end.

Cherry low-frequency compensation

I put this capability on the board because it's a current interest of mine and I think the technique needs to be more widely known. DC coupled circuits give a perfect square-wave response at low frequencies, but can suffer from dangerous DC offsets. Placing a capacitor in the lower arm of the feedback network of a non-inverting amplifier offers protection by reducing DC gain to unity, but a low frequency square wave, such as 20Hz, will suffer from a pronounced 'tilt' at the top and bottom of each cycle. Professor Ed Cherry devised a scheme to compensate for this by adding an extra RC network (see *ETI* magazine, *60W NDFL Amplifier*, May 1983). This technique can also be used to minimise the value of the capacitor, which can often be hundreds of microfarads in a power amplifier, down to say 47µF. This then allows longer-life tantalum capacitors to be used. For those worried about distortion, the capacitor can then be configured as a bipolar part by putting two capacitors back-to-back and applying a 5V bias voltage to the centre connection. A demonstrator circuit is given in Fig.25, the overlay in Fig.26 and the finished board in Fig.27.

Positive feedback

The vast majority of op amp circuits for audio, as well as instrumentation and other signal-processing designs, use

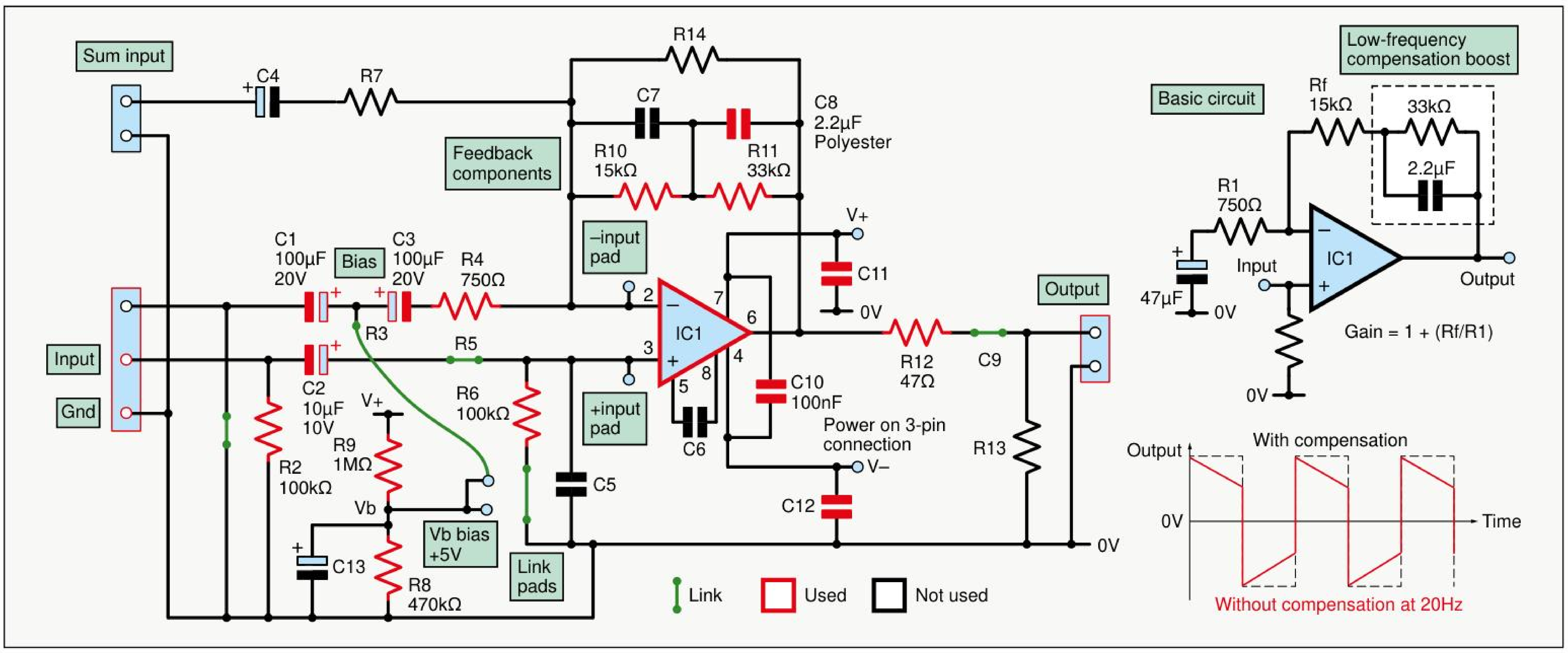

Sum input
C4
R7
R14
C7
C8
2.2µF
Polyester
Feedback components
R10
15kΩ
R11
33kΩ
C1
100µF
20V
Bias
C3
100µF
20V
R4
750Ω
–input pad
V+
C11
0V
Output
Input
Gnd
R3
R5
C2
10µF
10V
V+
R6
100kΩ
+input pad
IC1
C6
C10
100nF
Power on 3-pin connection
V–
R12
47Ω
C9
R13
R2
100kΩ
R9
1MΩ
Vb
C13
R8
470kΩ
Vb bias +5V
Link pads
C5
C12
0V
Link
Used
Not used
Basic circuit
Low-frequency compensation boost
Rf
15kΩ
33kΩ
2.2µF
R1
750Ω
47µF
0V
Input
IC1
Output
Gain = 1 + (Rf/R1)
0V
Output
With compensation
0V
Time
Without compensation at 20Hz

Fig.25. Circuit for demonstrating Cherry low-frequency compensation. Feed with a 20Hz square wave and short out the compensation network C8 and R11 to see the effect. The 'scope must be set to DC input coupling. Gain is 21x or 26dB.

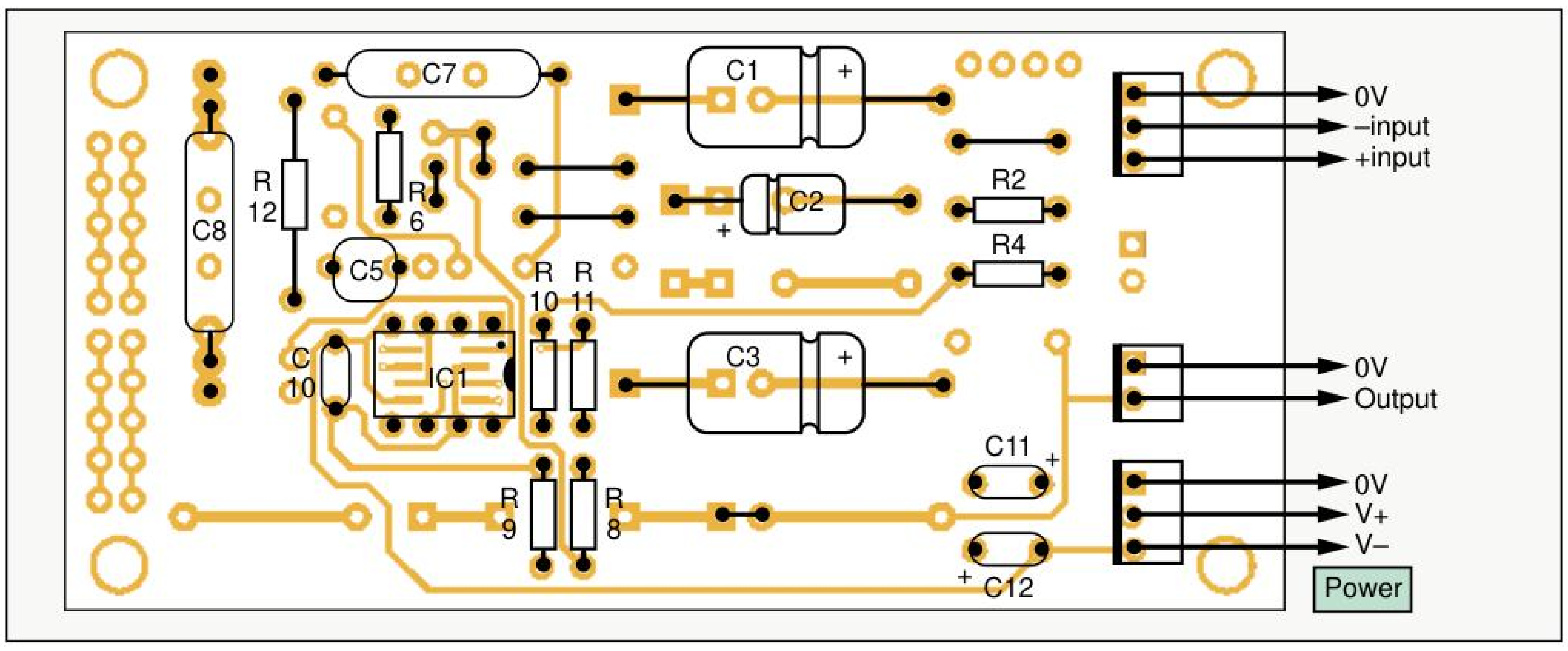

C7
C1
C8
R 12
R 6
C2
R2
R4
C5
R 10
R 11
C 10
IC1
C3
C11
R 9
R 8
C12
0V
–input
+input
0V
Output
0V
V+
V–
Power

Fig.26. Component placement for Cherry low-frequency compensated amplifier.

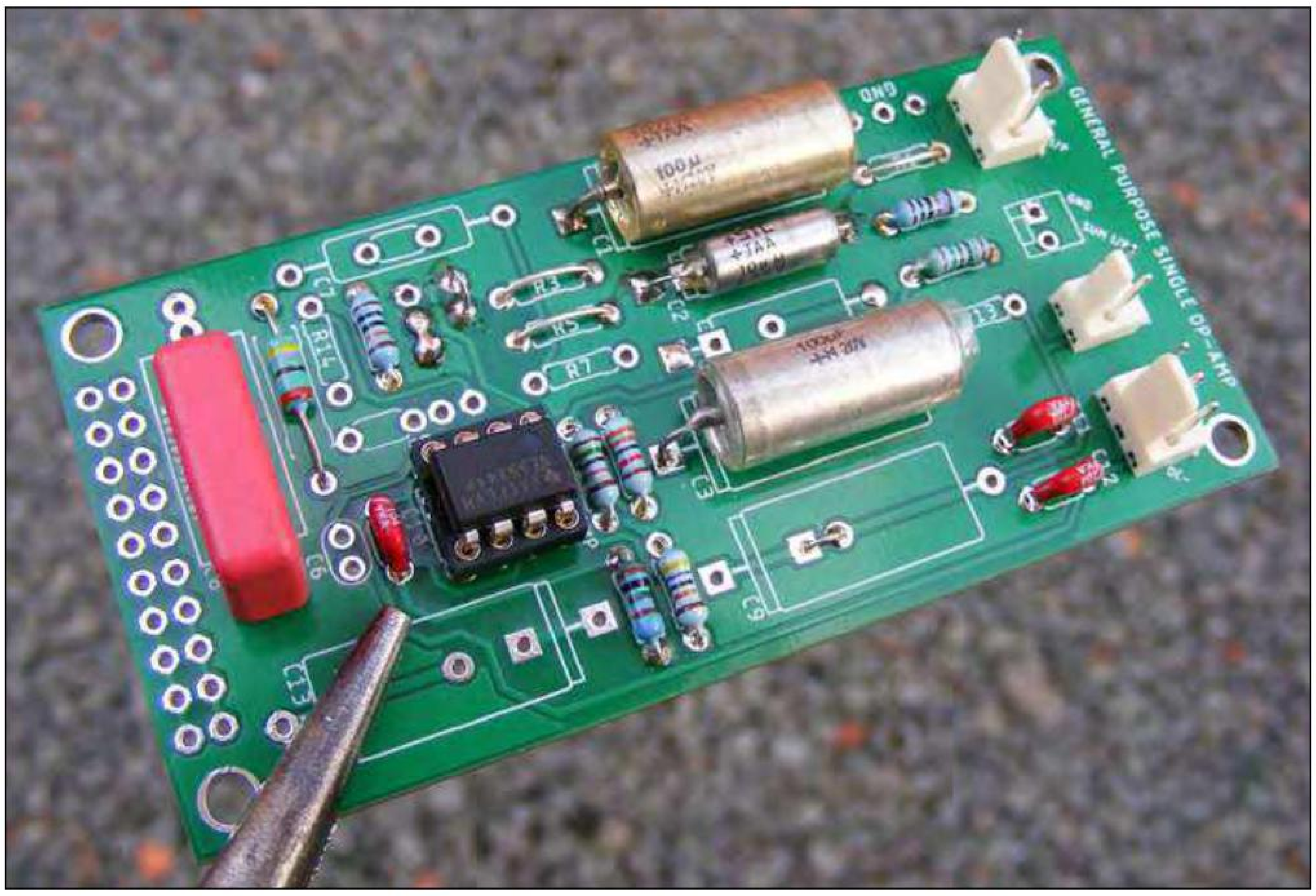


Fig.27. The final Cherry compensated op amp board. The big red capacitor (C8) provides a compensating low-frequency boost to compensate for the roll-off induced by the lower arm feedback capacitor (C1, C3) and associated resistor R4.

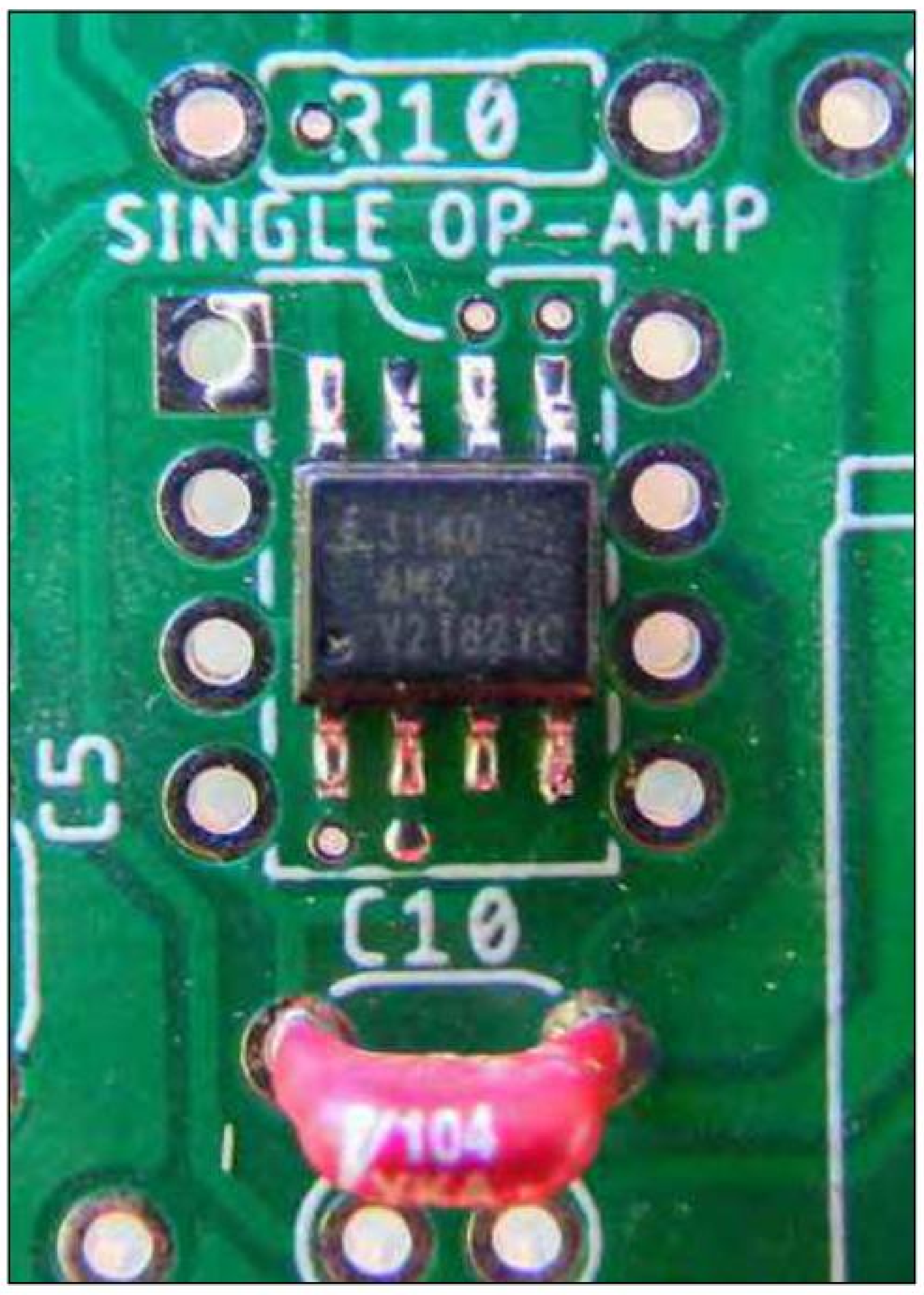

R10
SINGLE OP-AMP
C5
C10

Fig.28. There is provision for SMD op amps, such as this MOSFET CA3140.

negative feedback. Positive feedback is generally only used for oscillators, and comparators with snap-action hysteresis. This board does not really cater for these circuits, but I'm sure a way will be found.

Soldering on

There may come a time when some audio op amps are only available in surface-mount packs (heaven forbid), so the board includes a standard SOIC 8-pin outline in parallel with the DIP socket pins. This is shown in Fig.28.

Allowing for a few diagonal links, it should be possible to accommodate almost any audio op amp circuits, such as pre-emphasis/de-emphasis filters, integrator/servos, gyrators… and I've thought of about 20 more circuits. I'm sure readers will adapt the boards for themselves in ways limited only by their ESP (electronic spatial perception).

PCB for Universal single op amp board

The PCB described in this two-part series was designed by Mike Grindle and is available from the January 2023 section of the *PE PCB Service*, part no. AO1-JAN23.

AO*Shop*

The home for specialist audio, analogue and historic components – provided by Jake Rothman, *PE's Audio Out* columnist. The AOShop is your best bet for classic analogue 'NOS' (new old stock) components, including all parts for *Audio Out* projects and designs.

Ge semiconductors

Small-signal PNP transistors

AC125, NKT214F, OC57 OC59	**£1.00**

Low-noise PNP transistors

GET106	**£2.50**

Small power PNP transistors

AC153, AC153K, AC188	**£1.50**

High-voltage PNP transistors

OC77, CV7001, ACY20	**£1.50**

TO3 PNP power transistors

OC22, CV7054 (OC23), OC25, OC35, OC36, AD143, AD149, AD161, AD162	**£2.00**
AD140	**£3.50**
AD149 matched pair	**£5.00**

RF PNP transistors

OC41, OC42, 2SA12, 2SA53,AF124, AF128, GET872A	**£1.50**

NPN transistors

OC139, OC140, ASY73, AC141K, AC176K, AC176	**£2.00**

Diodes

CV7049 (OA10), CG92 (OA91)	**£0.50**

Si semiconductors

Diodes

ZC5800 RF Schottky	**£0.20**

Low-noise silicon transistors

BFW16A, 2SC3071	**£1.50**
2SC2204, 2SD655	**£0.50**
ZTX651	**£0.30**

RF transistors (suitable for Theremin)

BF199	**£0.50**
BF245	**£0.60**

Audio power MOSFETs

Exicon 10N20, 10P20	**£6.50**
Hitachi 2SJ99, 2SK343	**£3.50**
Hitachi 2SJ 50, 2SK135	**£7.00**
Hitachi 2SJ56, 2SK176	**£8.50**

JFETs

BFW11, BFW10, TIS73L, J177, J113, U1994, U1898, 2SJ176	**£1.00**

MOSFETs

ZVP2106A	**£0.30**
Dual-gate 3SK45, BFS28	**£1.50**

Metal-cased transistors

BC143	**£0.35**
2N1711	**£0.50**
BCY71	**£0.30**
BC109C	**£0.60**

Amplifiers

TL082 dual JFET input op amp	**£0.25**
LM318 high-speed op amp	**£0.35**
µA709 metal-cased op amp	**£2.00**
5534H metal-cased op amp	**£3.00**
LM384, TDA2030A	**£1.50**
TAA435 (power amp driver)	**£1.20**

Synthesiser ICs

That/dbx 2180 VCA/VCF	**£6.00**
CA3080 VCA/VCF (vocoder)	**£2.80**
CA3082 VCA/VCF	**£4.00**
LM13600/ LM13700 VCA/VCF	**£2.00**
CA3086 transistor array	**£1.00**
PT2399 echo/delay	**£1.50**

Dual transistors

2N2639, 2N2223, 2N2910 (NPN)	**£4.00**
E401 (JFET)	**£4.00**
DMMT3904/6	**£0.50**

Loudspeakers

PE Mini-Monitor

Volt PE165 6.5-inch woofer (each)	**£85**
Morel MDT29 tweeter (each)	**£25**
Kit *pair* of PE165/MDT29 plus Volt crossover parts and PCBs	**£299**
Monacor DT-28N tweeter (each)	**£45**
Vifa 19mm BC20SC15-04 tweeter (each)	**£15**
Volt PE110 5-inch woofer (each)	**£75**

Volt crossover inductors

1.2mH, 1.5mH, 2mH, 2.7mH, 0.5mH (tapped at 0.3mH) (each)	**£5.85**
LS3/5A transformer-core 15Ω assembled crossover board (each)	**£60**

Fully assembled and tested high-quality speaker prototypes – ask for details

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Vifa TC26 1-inch tweeter (each)	**£15**

Low-price speakers

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Philips 4-inch 4070	**£2.00**
EMI 10x6-inch, 30Ω Alnico	**£10**
64mm 64Ω neodymium	**£1.20**
3.5-inch 25Ω	**£3.50**
5x3-inch elliptical 50Ω or 80Ω Alnico	**£3.50**
1.65x2.75-inch 8Ω	**£1.50**

Can't see what you want? Just ask – we have a huge stock of inexpensive high-quality parts!

Capacitors

Note '10/63' denotes '10µF 63V'.

Polyester

3.3/100, 4.7/250, 4.7/63	**£1.00**
5.6/63, 8.2/63, 10/63	**£2.00**
Mullard 'Mustard' C296 0.22/400	**£2.00**

Polycarbonate

Axial 2.2/63 1%, 4.7/160, 6.8/63	**£1.00**

Radial

6.8/160V, 10/63	**£2.00**
Reclaimed 22/63	**£2.00**

Polystyrene

Philips 1% 4.7nF/160, 6.2nF/500, 12nF/63, 22nF/63, 110nF/63	**£1.00**
RIFA 1% 100nF/100	**£2.00**
Suflex 2.5% 10nF/63 (rad. or ax.)	**£0.50**

Radiation resistant

Siemens cellulose acetate MKL 2.2/25	**£0.80**

Electrolytic – Mullard blue 017 series

10/25, 22/25, 100/10	**£0.50**
150/40, 470/40,1000/40	**£1.00**

Tantalum – metal cased

22/50, 47/35, 68/25, 100/20, 120/10, 150/16, 220/10, 330/6	**£2.00**
22/35, 33/35, 47/20, 68/15, 100/10, 150/6	**£1.25**
4.7/50, 6.8/35, 10/25, 10/35, 22/15	**£1.00**

Moulded-case tantalum

Kemet axial 6.8/10	**£0.30**
Kemet radial 33/10	**£0.40**
STC radial 100/20	**£1.50**

Tantalum bead

22/50	**£1.00**
470/3	**£2.00**
680/6.3	**£3.00**

Wet tantalum

220/25 axial	**£3.20**
Castanet button 140/30, 470/3	**£3.20**
Hughes 540/10	**£3.20**

Bipolar

Hermetic bipolar tantalum 16/35	**£3.20**
Callins Elcap wet aluminium 10/50	**£0.50**

Philips solid-aluminium (axial) 121/123

47/16	**£1.00**
330/6.3	**£2.00**
100/35	**£4.00**

Philips Pearl 122 series (radial)

10/16	**£0.30**
10/25	**£0.50**

Silvered mica (radial)

4.7nF/500 5%	**£1.00**

Trimmer capacitors

Vishay plastic-film 4-40pF	**£0.80**
Vishay plastic-film 5.5-45pF	**£1.00**
Vishay plastic-film 5-80pF	**£1.20**
Vishay plastic-film 10-250pF	**£2.00**
Mica 1-12pF, 2-40pF	**£1.00**

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Eagle transformers

LT44, LT722 driver, LT700, LT723 500Ω output	**£2.50**
LT30 500mW output	**£3.50**

Repanco

T/T3 splitter transformer	**£4.00**
CH2 5mH RFC	**£2.00**

Balanced output transformer

Vigortronix 600Ω VTX-101-007	**£10**
Vigortronix 600Ω VTX-101-3001	**£10**
Vigortronix 600Ω VTX-101-3002	**£15**
Gardners 150Ω	**£10**
Reclaimed BBC LL74/MPC nickel core 600Ω	**£12**
Reclaimed mic input transformer	**£15**

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82µH, 4.7mH, 100µH, 270µH	**£2.00**
7-inch ferrite rod with MW and LW windings	**£3.00**

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Bourns wire-wound trimmer 5kΩ 3059 JM panel-mount	**£2.00**
Thermistor RA53, A13	**£4.00**
Thermistor CZ1, CZ6	**£1.50**
Holco H2 2.2MΩ 1W, 1%	**£1.00**
Welwyn 1GΩ 2W	**£1.00**
Allen Bradley 1.2kΩ 2W C-comp	**£1.00**

Lots of big valve resistors available.

Potentiometers

Bourns 81

25kΩ lin cermet	**£2.00**
25kΩ lin conductive plastic	**£3.00**

Plessey moulded-track

5kΩ log with switch	**£3.00**
50kΩ A/log	**£3.00**
Mil 250kΩ lin dual	**£5.00**

Alpha

16mm 4.7kΩ A/log	**£0.80**
220kΩ A/log	**£0.80**
10kΩ lin centre-detent dual-gang	**£1.50**

Allen Bradley J series/Honeywell 10kΩ lin 1 million cycles	**£5.00**
Blore Edwards AB 45 dual 5kΩ A/log with switch	**£3.50**
Alps RK9 dual-gang 5kΩ RD law	**£4.00**
BI P260 500kΩ log conductive plastic 1 million cycles	**£3.00**
Colvern wire-wound 100kΩ or 50kΩ dual-gang 3W	**£8.00**
Mil Spec hermetic 10Ω	**£8.00**

Miscellaneous

Theremin Clearance Sale!

Elysian Theremin MIDI box	**£300**

PCBs

Pocket Theremin (*EPE*, 1996)	**£4.00**
Elysian Theremin (*EPE*, 1996)	**£12**
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Make it with Micromite

Phil Boyce – hands on with the mighty PIC-powered, BASIC microcontroller

Part 43: Connecting more than one display to a PicoMite

OK, so this month's title is probably not what you were expecting, especially if you had started building *Part 1* of the *Fingerprint Reader*. Now for a confession, I seem to have somehow destroyed a second fingerprint module, and hence I've had to purchase yet another replacement. This is all rather ironic bearing in mind the first unit I received for free (since my supplier had sent it in error in place of a GPS module that I'd ordered – but said I could keep it). So, while I await delivery of what will be the third fingerprint module, this month we'll be discussing an alternative topic, one that I hope you'll find useful: how to use multiple displays with a PicoMite (or MicroMite). Why is this of interest? Remember, by design, MMBASIC's firmware is only capable of driving a single external display (the specific type being configured with `OPTION LCDPANEL`). So, how can we connect more than one display to a PicoMite?

Examples of use

First, let's acknowledge that there are some restrictions as to what is achievable when driving more than one display – but, once these limitations are understood, it will be possible to achieve some very creative multi-display projects. For example, how about adapting a project that uses multiple 7-segment LED modules and replacing each one with a small LCD display module. This would allow each 'digit' to offer endless options in terms of colour and font. Or how about building a data logger that has multiple sensors, and providing each sensor with a dedicated mini-display to show relevant data. Another idea would be to modify the *Micromite Robot's* animated eyes (that originally used two 8x8 LED matrix modules) and replace them with two coloured LCD displays; this would allow much more detailed eye effects to be animated.

Concept

The thought process when exploring this topic was as follows. If MMBASIC can send data to successfully drive a single display, then what is preventing a second identical display (connected to the exact same PicoMite pins) from displaying the exact same 'image'? Providing the displays are just receiving data from the PicoMite (and not sending data back to the PicoMite), then in theory you could connect multiple identical display modules to the PicoMite and they will all display the exact same image when the data is simultaneously received by them.

The reason we don't want to concern ourselves with data sent *from* a display module back to the PicoMite is because it makes the overall design much easier (and also eliminates any potential shorts that could occur between conflicting logic levels).

Now for an important point: the image on a display is only updated by MMBASIC graphical commands, such as `TEXT`, `BOX`, `CIRCLE`, `PIXEL`, `LINE`, `CLS`, `RBOX`, `POLYGON` and so on. Once the MMBASIC firmware has processed a graphical command and the PicoMite has sent the relevant data to the display(s), the updated image on the display(s) will remain in place until the next graphical command is sent (or until power is removed from the display modules). Put another way, there is no need to continually write data to the display(s) to maintain the image.

Having the same image on all displays isn't very useful since ideally we will want to control each display separately. However, if each display also has some form of 'enable' pin, then in theory, only the displays that are enabled would process the data sent out by the PicoMite.

So, theoretically, all we need to do for multiple display control is the following in terms of hardware:

- Connect all display modules (effectively in parallel) to the PicoMite in the usual manner apart from the 'enable' pin of each display
- Connect each 'enable' pin from each display to a dedicated PicoMite I/O pin.

Then, before using any graphical command, enable only the display module(s) that we want to receive *that* command by setting the relevant I/O pins to the correct state.

Now that the concept has been covered, we next need to understand any restrictions when choosing and using multiple displays with a PicoMite.

Restrictions

1. The first restriction is that all displays used in a multi-display project must be exactly the same type. This is because the MMBASIC firmware can only be set to a single type of display via the `OPTION LCDPANEL` command.
2. The second restriction is the type of interface that the identical displays use. Referring to the *PicoMite User Manual* (available for download from the January 2023 page of the *PE* website: **https://bit.ly/pe-downloads**), you will see that MMBASIC supports various LCD and OLED displays that use either a serial SPI, a serial I²C or a parallel interface. However, the way that serial I²C and parallel interfaces work means that the data line(s) are used for both writing to and reading from the display modules, and hence there will likely be contradictory logic levels present on the 'common' data lines when connecting displays together to the same pins. Only the SPI interface has a dedicated signal for writing data to the display. Thus, the second restriction is that only displays that use a serial SPI interface will work with the technique we're using here. To see this, think about the serial SPI interface as having three connections: SPI-Clk, SPI-Out and

5343A MICROWAVE FREQUENCY COUNTER
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19 999 994 243.

Fig.1. Frequency counters typically uses multiple 7-segment LED displays. This one has 11 digits, resulting in a display that is conveniently wide, but not too tall.

SPI-In. The PicoMite acts as the master and generates the SPI-Clk signal while transmitting any data that needs to be sent to the displays via the PicoMite's SPI-Out pin (to the display's SDA pin). The PicoMite's SPI-Out pin only sends data to the display(s) and there is no risk of any logic-level shorting. Note that the SPI-Out pin has nothing to do with any data that a display might want to send to the PicoMite. Because we want to avoid any potential logic-level shorts in our application, we will not be receiving data from the display modules, and hence we will not be connecting anything to the PicoMite's SPI-In pin. If we were to connect more than one display to the single SPI-In pin, and if more than one display module were to be enabled, then logic-level shorting would likely occur. Hence, we won't read data from any display.

3. Since we can't read data from any of the displays, certain graphical commands (that require data to be read from the display) will not work. For example, the `BLIT` command that is used to copy one area of the display to another is unavailable; likewise, transparent text.

Understanding the above restrictions means we can now experiment with the concept; but first, let's choose a multi-screen application.

Simple counter

Traditionally, multiple red 7-segment LED displays would be used to build a counter display since the displays are cheap and are bright enough to read clearly, especially when mounted behind a red filter. Six, eight or even 10 digits is not uncommon when used in something like a professional frequency counter (see Fig.1).

If we wanted to build a frequency counter based on a PicoMite (a great idea for a future article), we could simply choose to implement a single large LCD screen. If the large screen is used in landscape mode, then it would allow for a sufficient number of digits to be displayed across the screen. However, the proportions of the screen would make it larger in height than we really need; so instead, let's consider using multiple small LCD displays for each digit.

We are not going to build a frequency counter as such, but let's take the idea of building a simple 4-digit counter comprising four displays; each one displaying a single digit and all driven by a single PicoMite. Four identical sub-displays means we can create an overall display that is wide enough, but not excessively high. Ideally. we want digits that are about 25mm (1 inch) high, which will be easy to read from a distance.

Now we know what we are trying to achieve, let's choose a suitable display.

ST7735S module

The ST7735S (see Fig.2) is one of our favourite mini displays that is compatible with the PicoMite, plus it meets all our requirements:

- SPI interface
- 'Enable' pin in the form of a 'ChipSelect' (CS) pin
- Compact size: 0.96-inch

Furthermore, it is an IPS display, which means it provides a nice clear and bright image that is viewable from most angles (much better than an ordinary LCD display). It is reasonably cheap – some well-known online sites offer it at under £1.50 per unit, although around £5 each is more common from UK suppliers. So, this is the screen we will use for our counter demo.

Fig.2 shows the ST7735S has just eight connections, as follows:

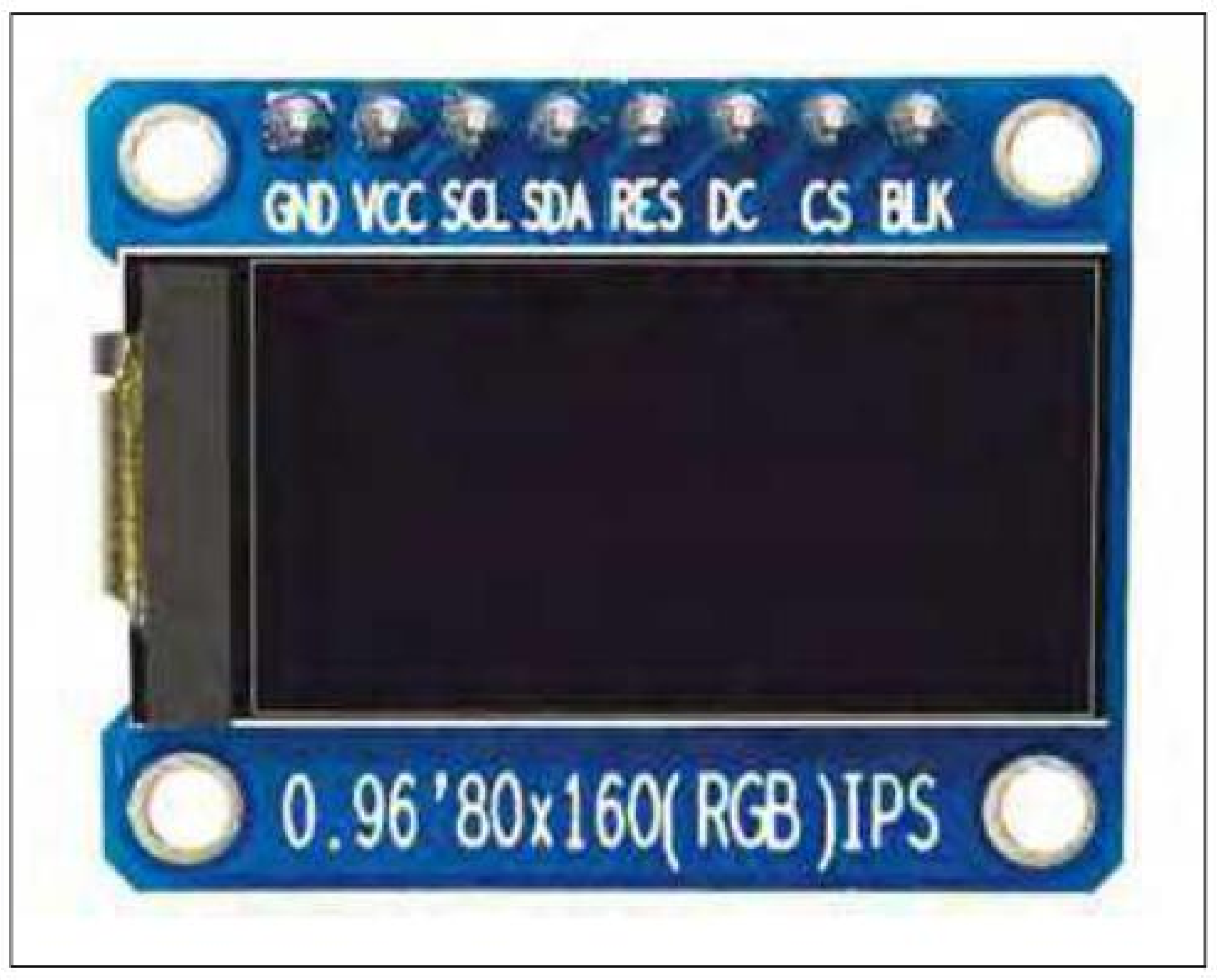

Fig.2. The ST7735S module is an 0.96-inch IPS display module with a pixel resolution of 160x80.

1. **BLK** (Backlight) – connect this to any I/O pin (defined as a parameter in the `OPTION LCDPANEL` command) which will then control the brightness of the display via the `BACKLIGHT` command.
2. **CS** (ChipSelect) – the 'Enable' pin. When low, the display is enabled. Defined as a parameter in the `OPTION LCDPANEL` command.
3. **DC** (Data/Command) – connect to any available I/O pin. Defined as a parameter in the `OPTION LCDPANEL` command.
4. **RES** (Reset) – when low, the display is reset. Connected to any available I/O pin and defined as a parameter in the `OPTION LCDPANEL` command.
5. **SDA** (SPI Data In) – connect to the PicoMite's SPI-Out pin (defined as a parameter in the `OPTION SYSTEM SPI` command).
6. **SCL** (SPI Clock) – connect to the PicoMite's SPI-Clk pin (defined as a parameter in the `OPTION SYSTEM SPI` command).
7. **VCC** (3-5V) – connected to 3.3V in our application (can also be connected to 5V to give a brighter display image)
8. **GND** – connect to PicoMite's GND pin.

A point to make here is that the MMBASIC firmware drives pins 1-6 (once two `OPTION`s have been configured). The remaining two pins simply provide power to the display.

Demo 1

We will begin by connecting multiple screens in parallel to check that we can write to all displays simultaneously so that they display the exact same image.

The easiest way to assemble this circuit is to use a small piece of stripboard

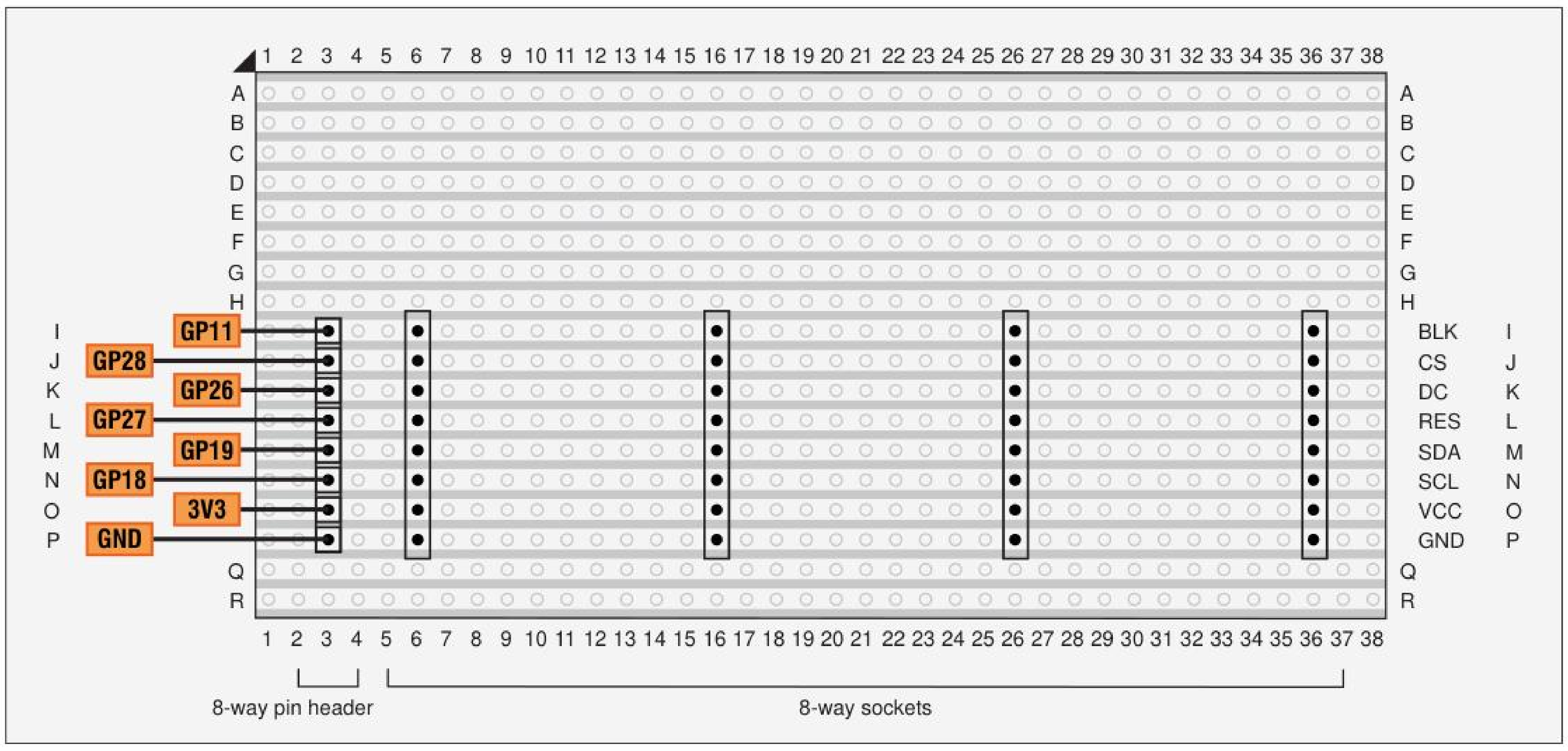

Fig.3. Four ST7735S modules are mounted in parallel on a piece of stripboard.

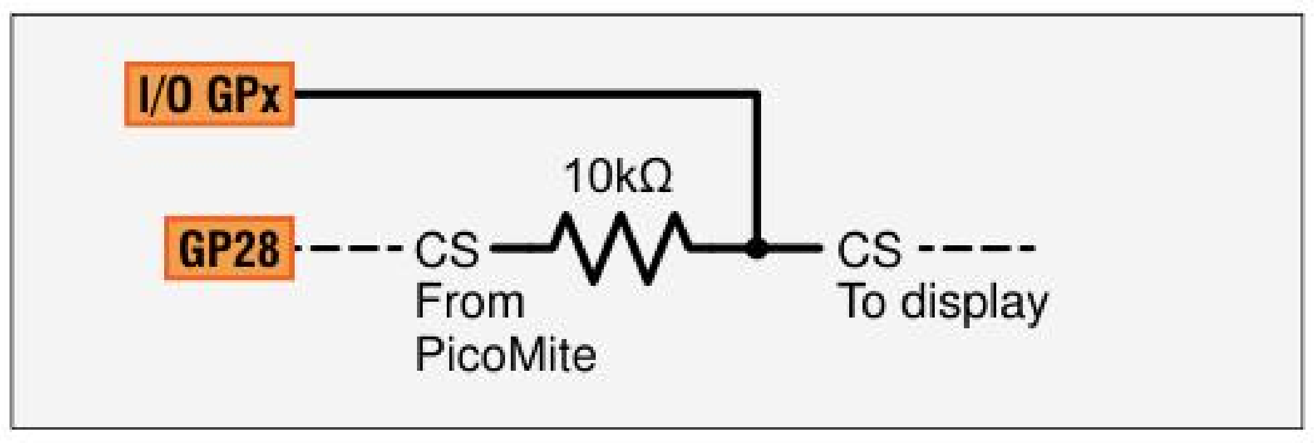
I/O GPx
10kΩ
GP28
CS
From
PicoMite
CS
To display

Fig.4. When the I/O pin is set high, the display is disabled (because CS is high). However, when the I/O pin is floating (`SETPIN GPx, OFF`), then the CS signal from the PicoMite can control the display's CS line. The 10kΩ resistor prevents device damage when the I/O pin is set high and CS is driven low by the PicoMite.

since all we need to do is mount four 8-way sockets so that all displays are connected to each other in parallel. Refer to Fig.3 for how we prepared our stripboard. The 8-way pin header on the left is used with eight female-to-female DuPont leads to connect it to the PicoMite. Once everything is connected and you have correctly inserted multiple ST7735S display modules, connect the PicoMite to your computer so that you can configure MMBASIC to work with the ST7735S. To do this, you just need to set two `OPTION`s as follows:

- *`OPTION SYSTEM SPI CLKpin, MOSIpin, MISOpin`*
  by using: **`OPTION SYSTEM SPI GP18, GP19, GP16`**
- *`OPTION LCDPANEL ST7735S, orientation, DC, RESET, CS, Backlight`*
  by using: **`OPTION LCDPANEL ST7735S, P, GP26, GP27, GP28, GP11`**

Once this is done, type any graphical command to check that all displays behave in the same way. For example, type `CLS RGB(GREEN)` and observe what happens. If all screens turn green, then you have successfully completed the first step. However, if things don't work as expected, visually check the eight connections to the PicoMite, and also check the two `OPTION`s have been configured correctly by typing `OPTION LIST`. If either `OPTION` is incorrect, type `OPTION RESET` and carefully re-enter both `OPTION`s again. Also check that there are no shorts between adjacent tracks on the stripboard. Once you see the correct response to any graphical command, check that you can adjust the brightness by typing `BACKLIGHT 25`. This should noticeably dim the display. Type `BACKLIGHT 100` to return to full brightness. If the display's brightness is unaffected by the `BACKLIGHT` command then check the connection between pin GP11 and the BLK pins on the displays. Also check the last parameter in `OPTION LCDPANEL` is indeed set to `GP11`.

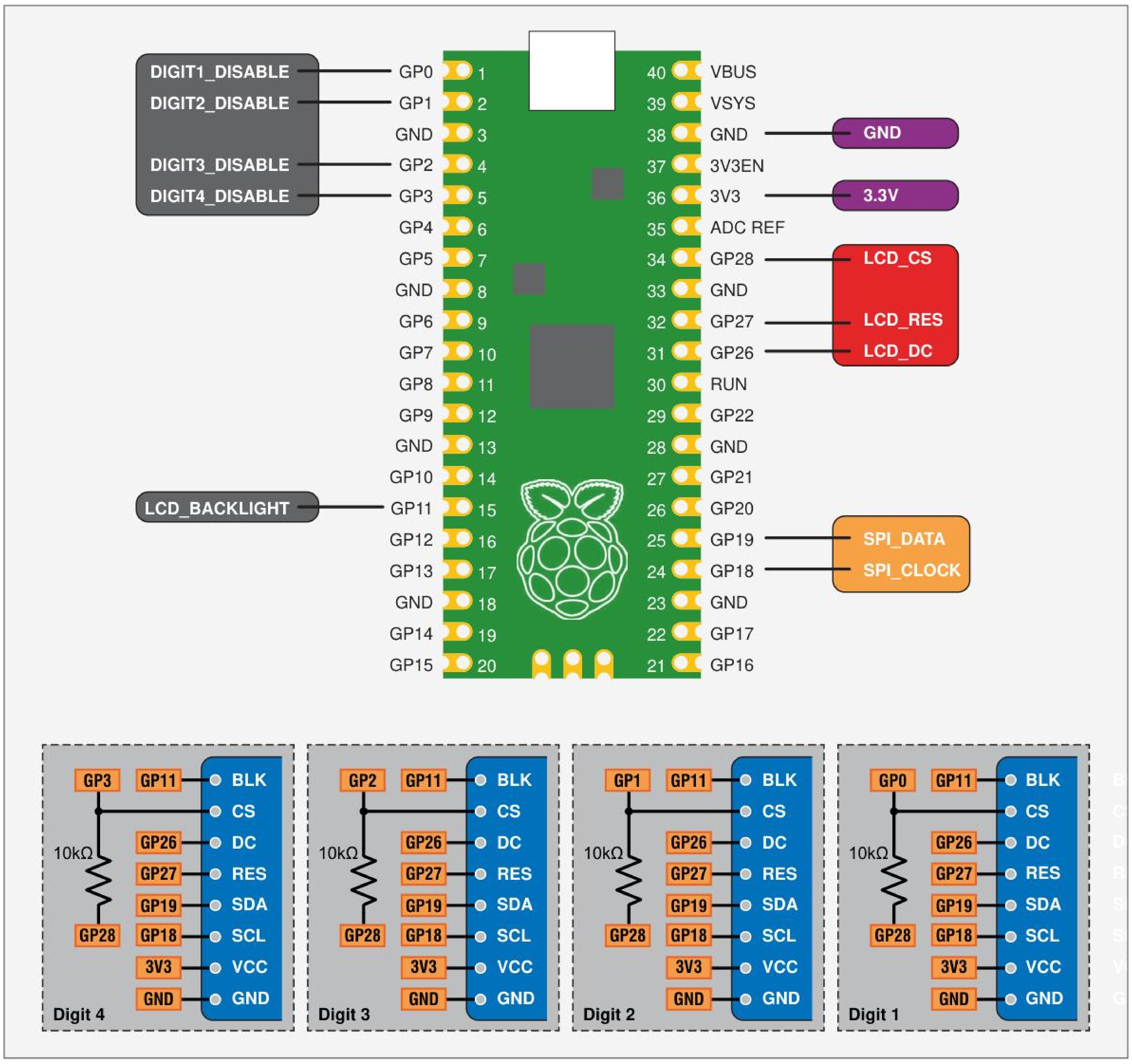
DIGIT1_DISABLE
DIGIT2_DISABLE
DIGIT3_DISABLE
DIGIT4_DISABLE
LCD_BACKLIGHT
GP0 1
GP1 2
GND 3
GP2 4
GP3 5
GP4 6
GP5 7
GND 8
GP6 9
GP7 10
GP8 11
GP9 12
GND 13
GP10 14
GP11 15
GP12 16
GP13 17
GND 18
GP14 19
GP15 20
40 VBUS
39 VSYS
38 GND
37 3V3EN
36 3V3
35 ADC REF
34 GP28
33 GND
32 GP27
31 GP26
30 RUN
29 GP22
28 GND
27 GP21
26 GP20
25 GP19
24 GP18
23 GND
22 GP17
21 GP16
GND
3.3V
LCD_CS
LCD_RES
LCD_DC
SPI_DATA
SPI_CLOCK
GP3
GP2
GP1
GP0
10kΩ
GP28
GP11
GP26
GP27
GP19
GP18
3V3
GND
BLK
CS
DC
RES
SDA
SCL
VCC
GND
Digit 4
Digit 3
Digit 2
Digit 1

Fig.5. Circuit diagram showing how the four ST7735S displays are connected to a single PicoMite.

The next step is to modify the stripboard so that we only control displays that are 'enabled'. Before we do this, let's first explore how to modify the CS pin so that we can use a dedicated I/O pin (one per display) to effectively enable (or disable) the display.

Modifying the CS signal

Currently, the CS pin from the PicoMite drives each CS pin simultaneously on all four displays (and that is the reason they all display the same image). We need a way of holding any display's CS pin high whenever we want to 'disable' those displays from responding to the data that is being sent from the PicoMite (from the PicoMite's SPI-Out pin simultaneously to all the SDA pins). By using a dedicated I/O pin, we can hold an individual display's CS pin high, and then that particular display won't respond to any SPI data that it receives. But we also need a way of 'releasing' the logic-high from the display's CS pin whenever we want the display to respond to the SPI data. Refer to Fig.4 to see how we can achieve this with a single I/O pin (GP0), and a single 10kΩ resistor to control one display. This circuit is repeated four times, one for each display's CS pin – in other words, we will need four I/O pins, and four 10kΩ resistors for our four-digit counter.

Display operation

With the I/O pin (eg, GP0) in a floating state (`SETPIN GP0,OFF`), the display's CS pin is controlled by the CS output from the PicoMite. In other words, the display behaves normally. Note that the 10kΩ resistor has no impact on the logic level received on the display's CS pin. However, if we now set GP0 to a high logic level (with `SETPIN GP0,DOUT` and `PIN(GP0)=1`) then the CS pin for that display is held high and hence the display is disabled and will ignore any data received on its SDA pin. In this scenario, the 10kΩ resistor ensures that the CS signal from the PicoMite is not shorted by the logic high from the GP0.

In summary, with GP0 floating, the display is enabled (and will respond to data), but with GP0 set high, the display will be disabled (and ignore any data) – it's that simple! Fig.5 shows an overview

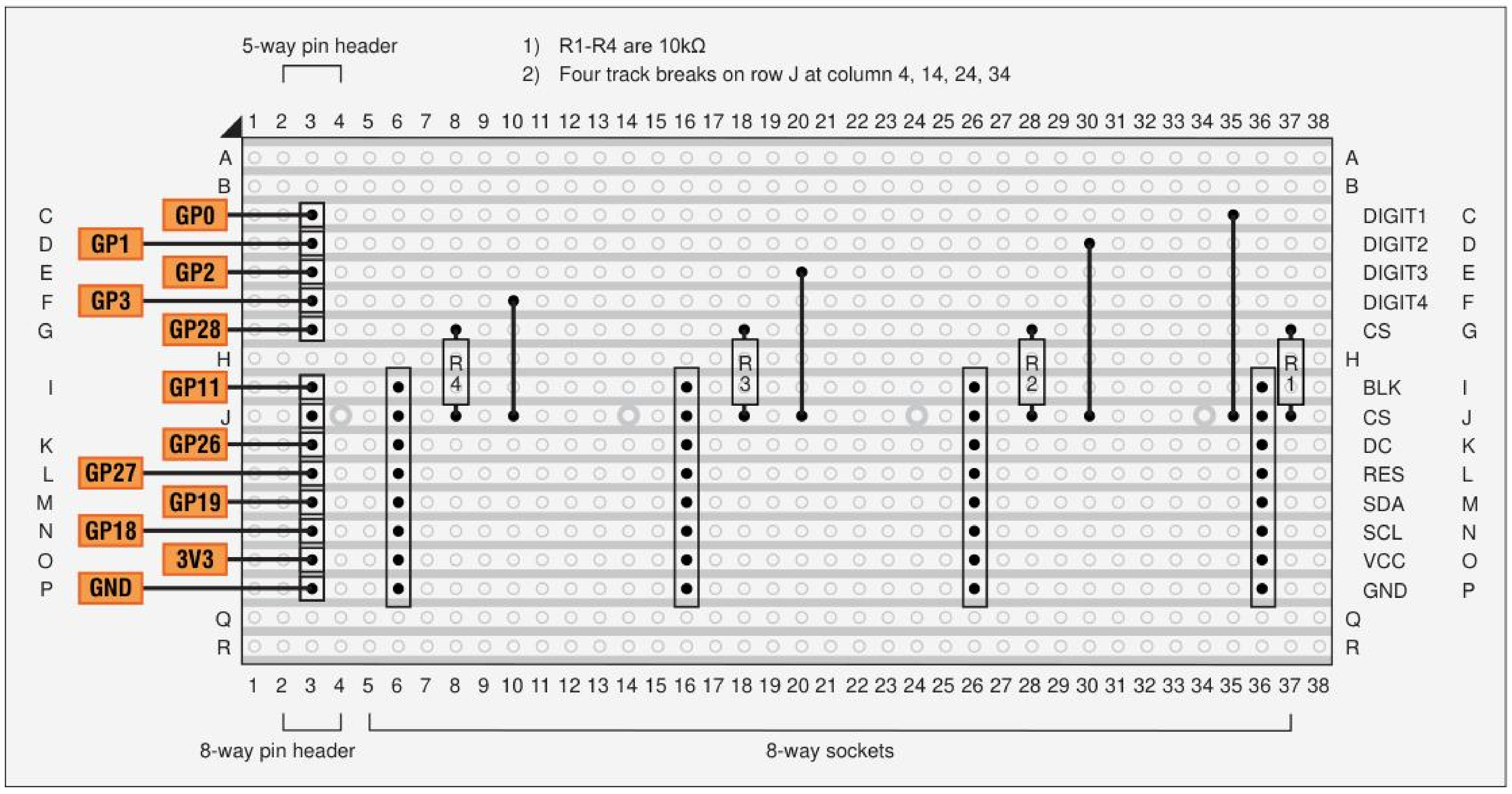

Fig.6. The modifications to the stripboard for individual control of each ST7735S display.

of all the required pin connections that we'll be using in our simple counter.

Modifications to stripboard

See Fig.6 for the changes that are required for the stripboard, comprising the following:

- Make four track cuts
- Add a five-way pin header
- Insert four wire links
- Add four 10kΩ resistors.

Before modifying the stripboard, remove all the displays to avoid accidental damage. Once the changes have been made, perform a visual check to ensure there are no track shorts and the four track cuts are made correctly. Once all looks good, re-insert the displays, and connect the PicoMite to the two headers, as shown in Fig.6 (left-hand side).

Demo 2

Once the CS signal modifications have been made on the stripboard, and everything has been connected, you should test that everything works correctly by running the **Demo2.txt** program (available for download from January 2023 page of the *PE* **website**). Install the program into your PicoMite and observe what happens when you `RUN` the program. If all is working, you will see a counter like that shown in Fig.7. Do makes sure that you look at the code to see exactly how the DISABLE and ENABLE subroutines control the CS line, as outlined in Fig.4 (and described above in the section *Modifying the CS signal*).

In essence, before issuing any graphics command, ensure you enable each display that you want to respond, and disable all the others. Note that one, some or all can be enabled/disabled at any one time, producing a flexible solution for driving multiple displays from a single PicoMite.

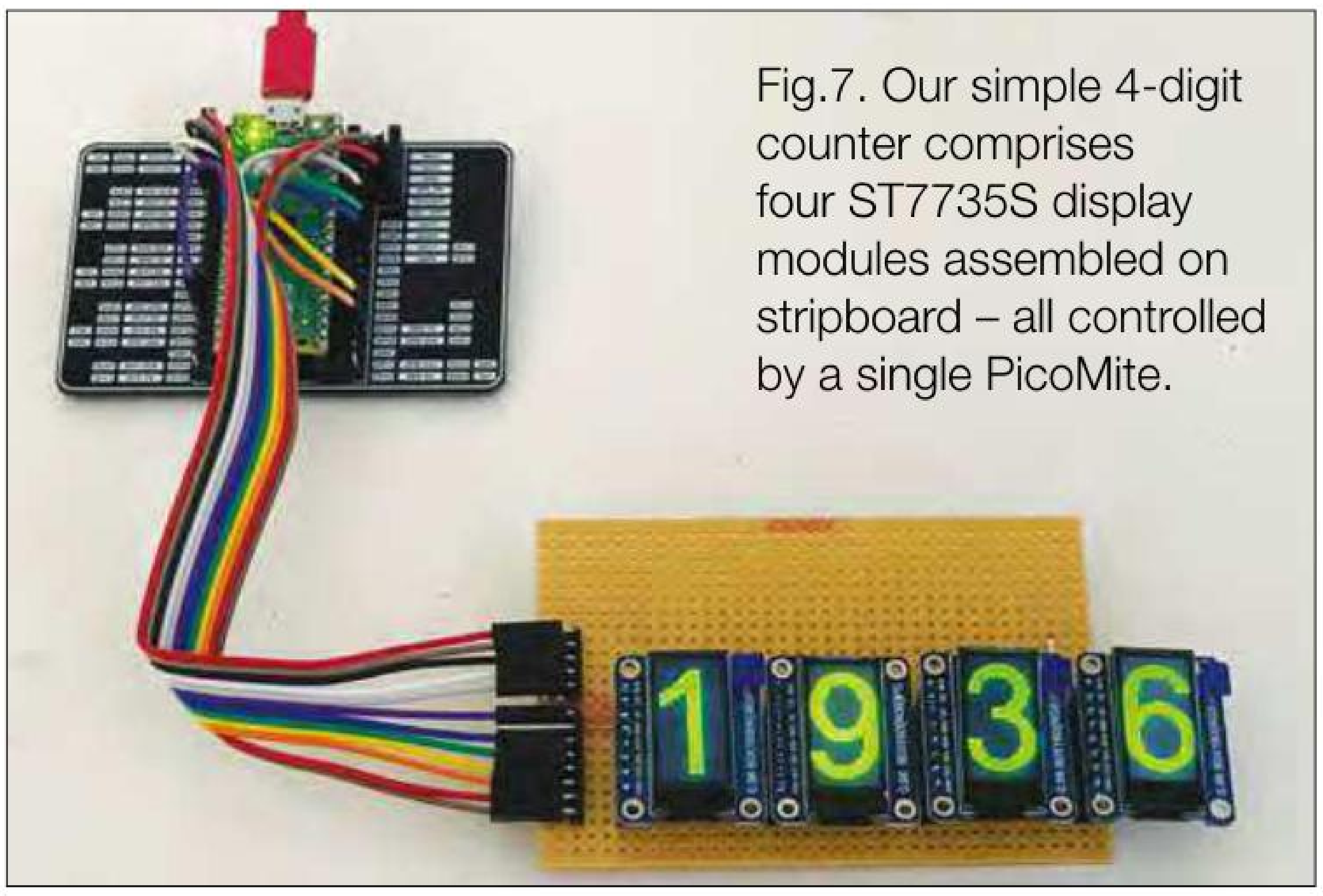

Fig.7. Our simple 4-digit counter comprises four ST7735S display modules assembled on stripboard – all controlled by a single PicoMite.

Challenge

Having seen how easy it is to write to each individual display module, how about challenging yourself to see if you can adapt the *Demo2* counter into displaying a simple clock (hours and minutes from the inbuilt `TIME$` string variable). Alternatively, connect four temperature sensors to the PicoMite, and then map each sensor to its own display. And if you're feeling ambitious, why not have a go at creating some kind of game. Whatever your creative juices come up with, do send us an email if you end up building something interesting.

Next time

Fingers crossed – the replacement fingerprint module will arrive soon to complete *Part 2* of the *Fingerprint Reader* project.

Until then, stay safe, and have FUN!

Questions? Please email Phil at:
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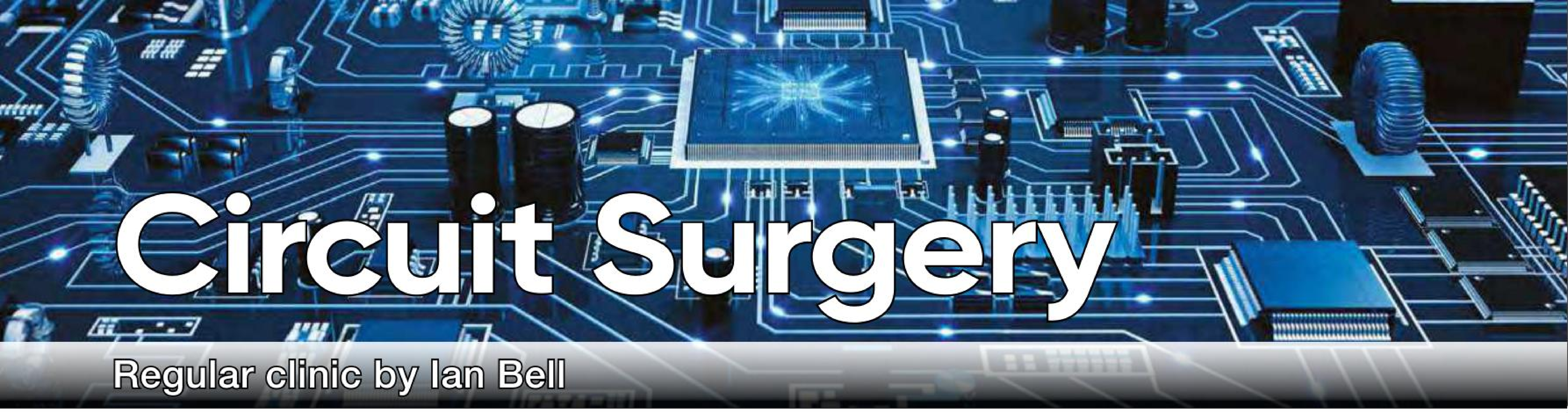


Circuit Surgery

Regular clinic by Ian Bell

Electronically controlled resistance – Part 5

In this issue, we continue our series on electronically controlled resistance. Last month, we started looking digipots – digital potentiometers – which are integrated circuits providing a similar function to mechanical potentiometers and trimmers. They are commonly interfaced to microcontrollers to adjust system parameters such as gain and bias voltage. We introduced the basic principles of digipots and discussed some example ICs which demonstrate some of the characteristics and functionality that are available.

Prior to digipots we were looking at JFETs as voltage-controlled resistors, including a number of simulation examples using LTspice. There was no significant issue with setting up simulations using JFETs as electronically controlled resistors because JFETs are basic devices in SPICE simulation, and models for both generic and specific commercial devices are readily available. Digipots are more complex integrated circuits for which models may not be available from the manufacturer (although some are). This month, we will consider some approaches to simulating digipots in LTspice and at the same time discuss a couple of key non-ideal digipots characteristics (and how to simulate them as well).

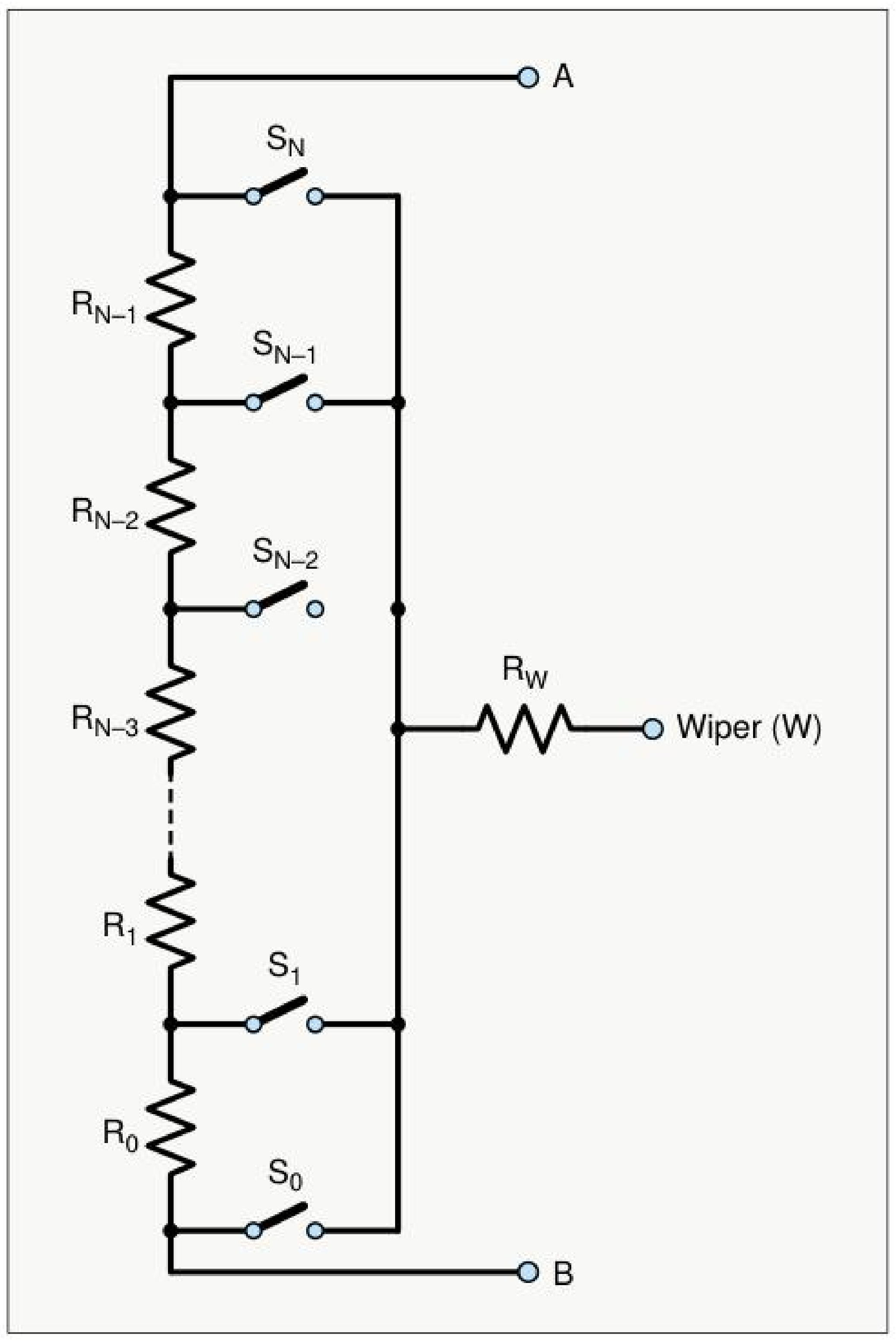

A
S_N
R_{N-1}
S_{N-1}
R_{N-2}
S_{N-2}
R_{N-3}
R_W
Wiper (W)
R_1
S_1
R_0
S_0
B

Fig.1. Circuit structure of a digipot.

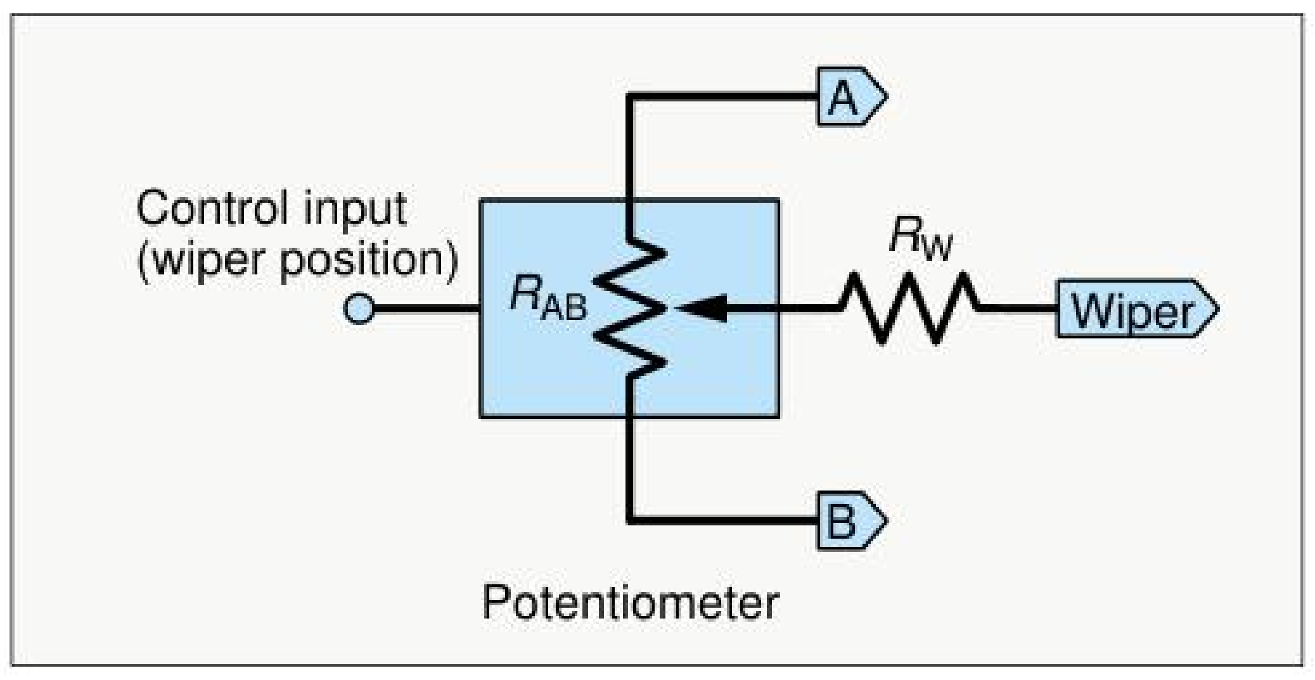
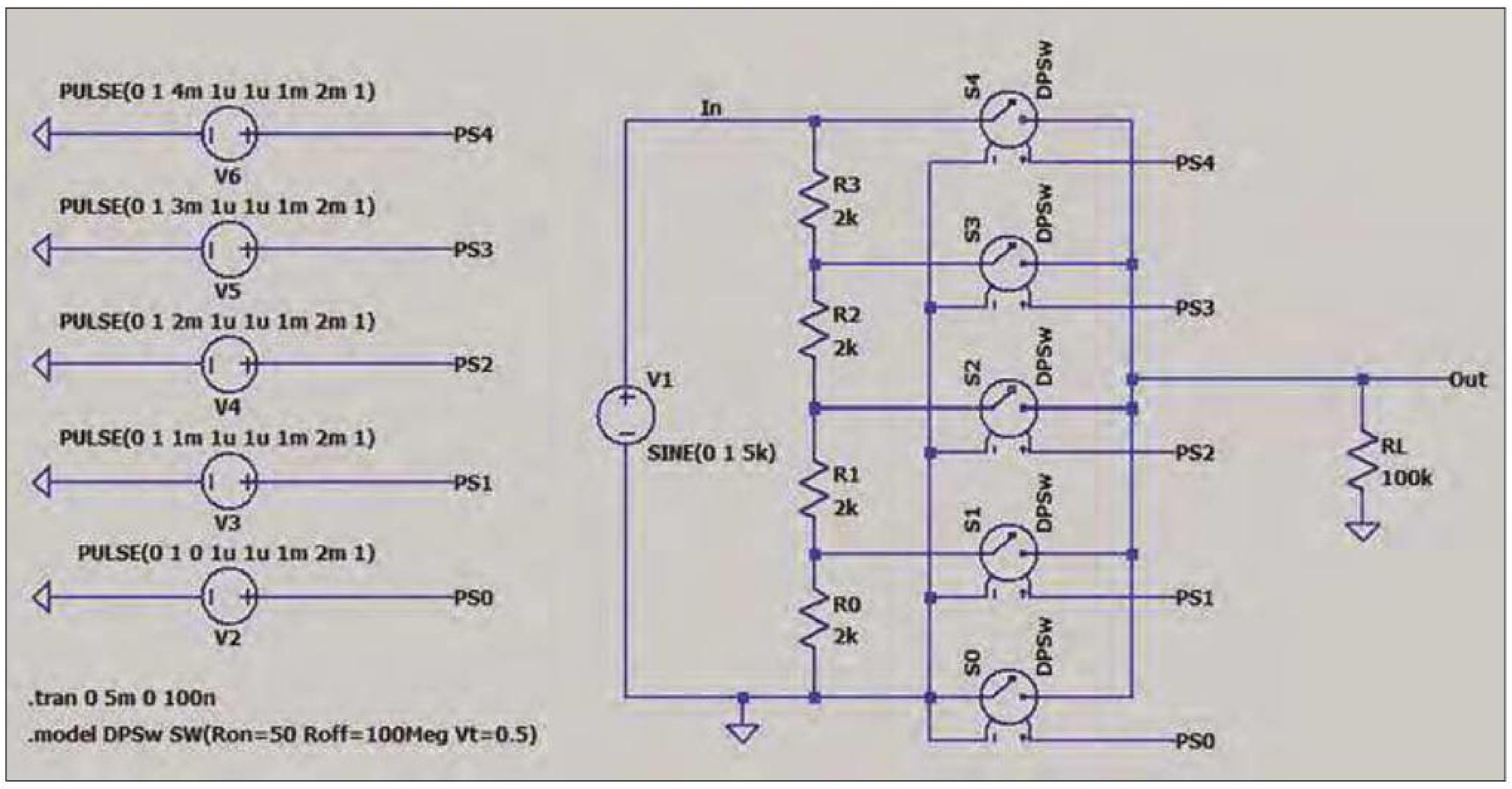

A
Control input
(wiper position)
R_{AB}
R_W
Wiper
B
Potentiometer

Fig.2. Digipot equivalent circuit.


PULSE(0 1 4m 1u 1u 1m 2m 1)
V6
PS4
PULSE(0 1 3m 1u 1u 1m 2m 1)
V5
PS3
PULSE(0 1 2m 1u 1u 1m 2m 1)
V4
PS2
PULSE(0 1 1m 1u 1u 1m 2m 1)
V3
PS1
PULSE(0 1 0 1u 1u 1m 2m 1)
V2
PS0
In
V1
SINE(0 1 5k)
R3
2k
R2
2k
R1
2k
R0
2k
S4
S3
S2
S1
S0
DPSw
PS4
PS3
PS2
PS1
PS0
Out
RL
100k

```
.tran 0 5m 0 100n
.model DPSw SW(Ron=50 Roff=100Meg Vt=0.5)
```

Fig.3. LTspice digipot schematic using basic SPICE elements.

Fig.1 shows the structure of a digipot resistor ladder and switch network, which was discussed in some detail last month. In this schematic we have included the wiper resistance, which is a non-ideal characteristic exhibited by real digipots. The wiper resistance is due to the on resistance of the MOSFET transistors used

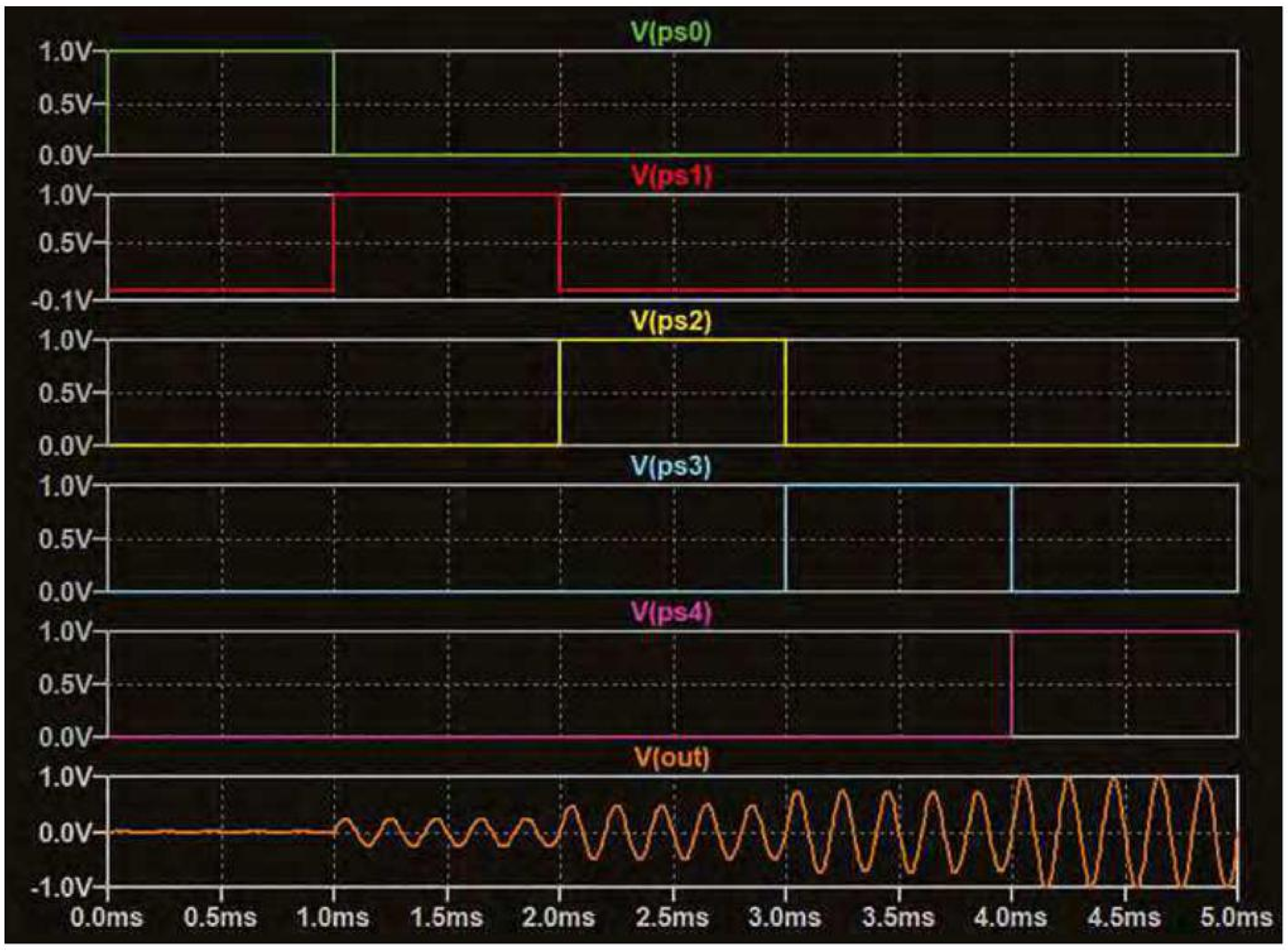


Fig.4. Results from simulation of the circuit in Fig.3.

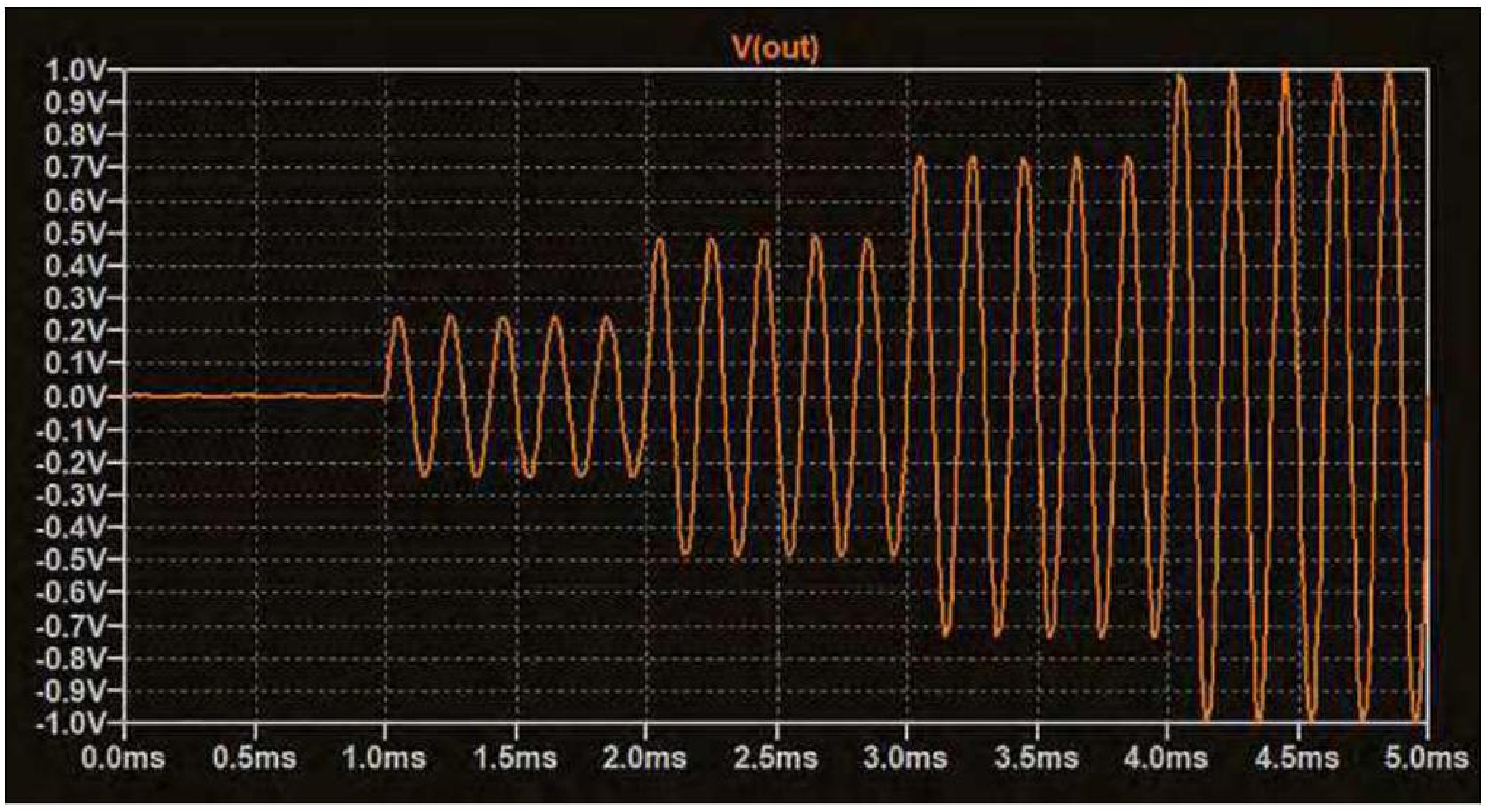
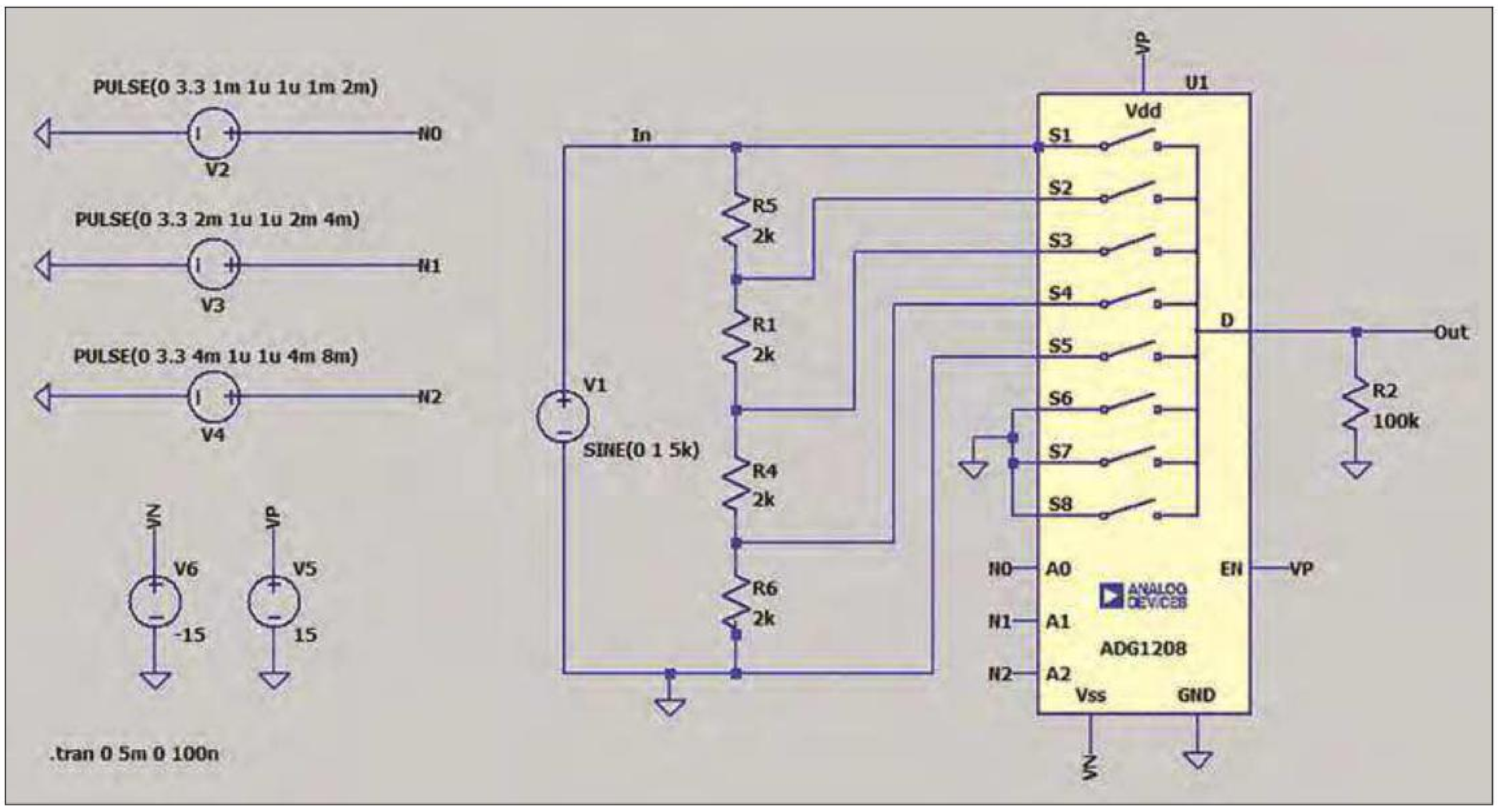


Fig.5. Larger view of output voltage (bottom trace in Fig.4).



```
.tran 0 5m 0 100n
```

Fig.6. LTspice digipot schematic using an ADG1208 multiplexer to implement the switches.

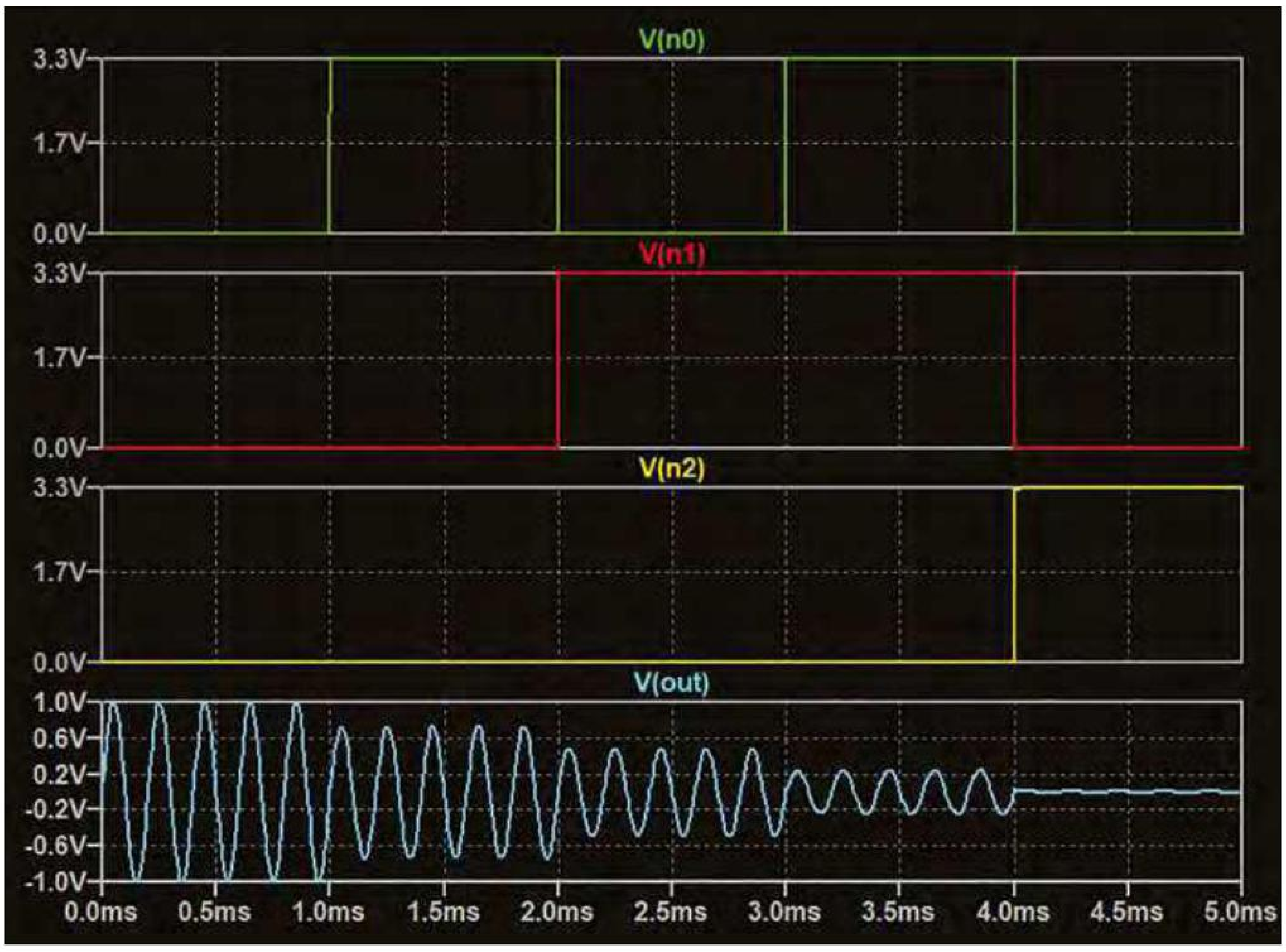


Fig.7. Results from simulation of the circuit in Fig.6.

to implement the wiper position switches (S_0 to S_N in Fig.1). Strictly speaking, there is a different resistance for each switch, so this a simplified representation. Fig.2 shows the equivalent circuit of the digipot in Fig.1 – it is drawn as a potentiometer of resistance *R* and a control signal to set the wiper position (in practice this is a digital code which selects one of the switches S_0 to S_N to be on). The wiper resistance is also shown. The total resistance between A and B (R_{AB}) is the sum of the individual resistors R_0 to R_{N-1}. This is the resistance of the digipot, with commonly available values ranging from 5kΩ to 100kΩ.

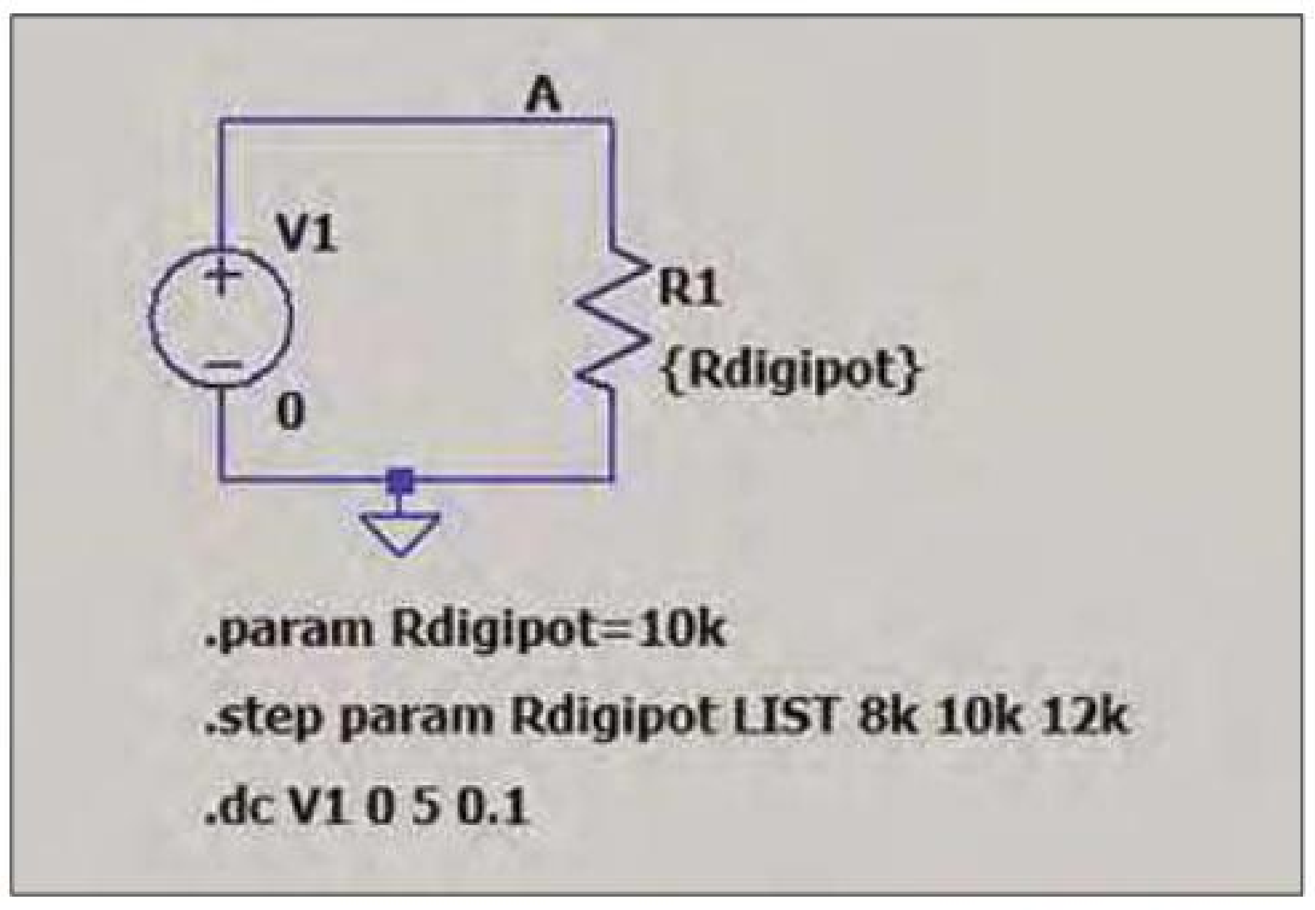
Digipot simulation approaches

When simulating a digipot we can either try to create a circuit close to the implemented structure, as shown in Fig.1, or use a more abstract model, similar to the circuit in Fig.2. We will start with the former – Fig.3 shows an implementation of the circuit in Fig.1 (for $N = 4$) using basic SPICE elements – resistors and switches. The switches are implemented using the voltage-controlled switch element ('sw' symbol in the component selector). The simulation applies a 1V peak 5kHz sinewave to the digipot circuit. `RL` is a load resistor – since it is much larger than digipot resistors it will not have much effect.

The switch requires a model to specify its parameters – here we use the model name `DPSw` (digipot switch). The model sets the switch on resistance (`Ron`) to 50Ω, which models the wiper resistance. The switch off resistance (`Roff`) is 100MΩ. The `Vt` model parameter is the switch threshold voltage. It is set to 0.5 and is used with control waveforms which switch been 0V (off) and 1V (on). The switches are controlled, via the `PS0` to `PS5` signals, by five pulse voltage sources which switch the five switches on for 1ms each in sequence.

Using analogue multiplexer switches

The results of the simulation are shown in Fig.4, and Fig.5 shows a larger view of the output waveform so that the amplitude steps obtained by different wiper positions can be more clearly seen. The circuit in Fig.3 works well but is not particularly convenient – it requires each switch to be individually controlled, when ideally, we want a digital code or a voltage to represent the code value as the control input. This issue can be overcome by using an analogue multiplexer integrated circuit model to implement the switches. There are a few of



```
.param Rdigipot=10k
.step param Rdigipot LIST 8k 10k 12k
.dc V1 0 5 0.1
```

Fig.8. Simple LTspice schematic to illustrate component value variation.

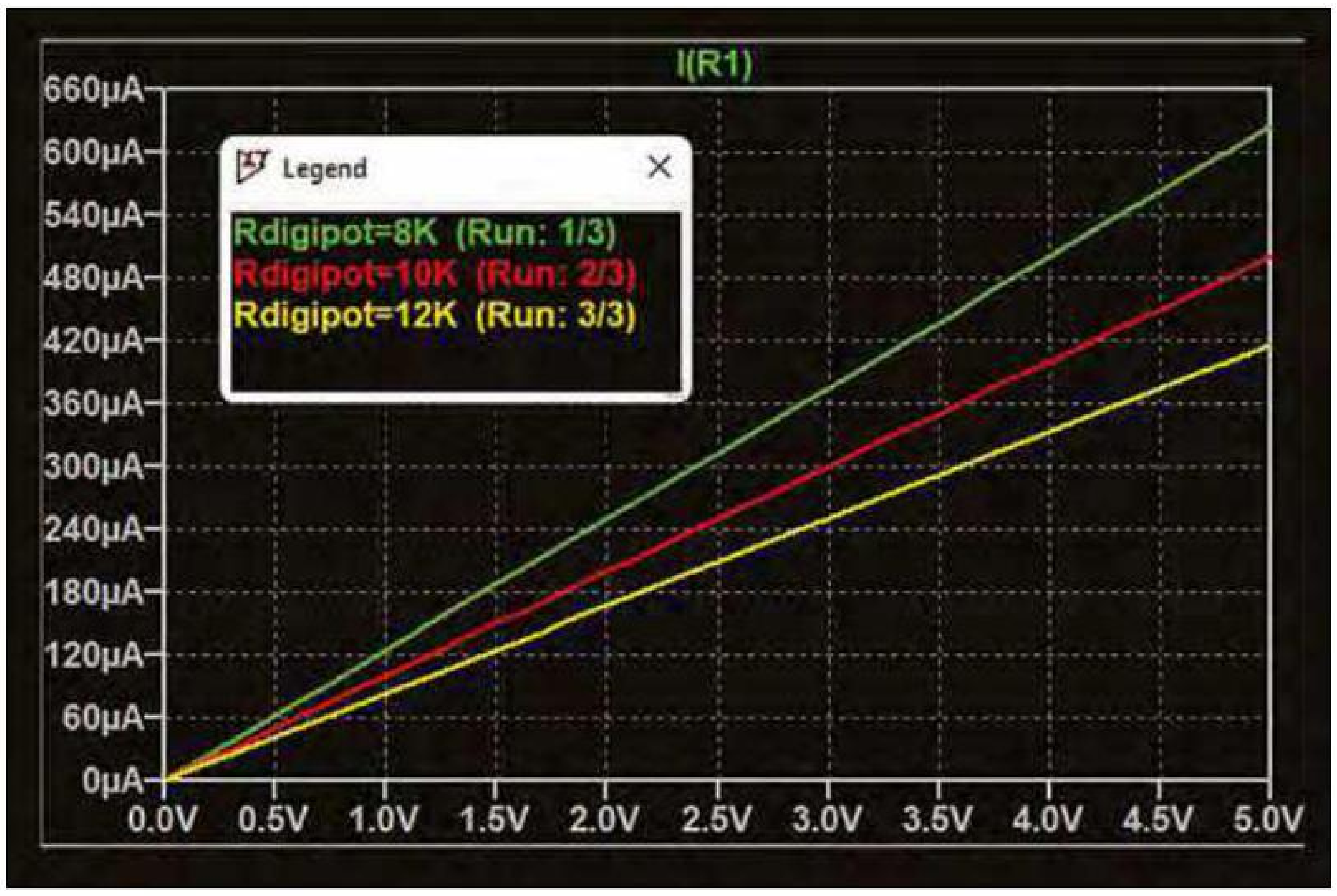


Fig.9. Results from simulation of circuit in Fig.8.

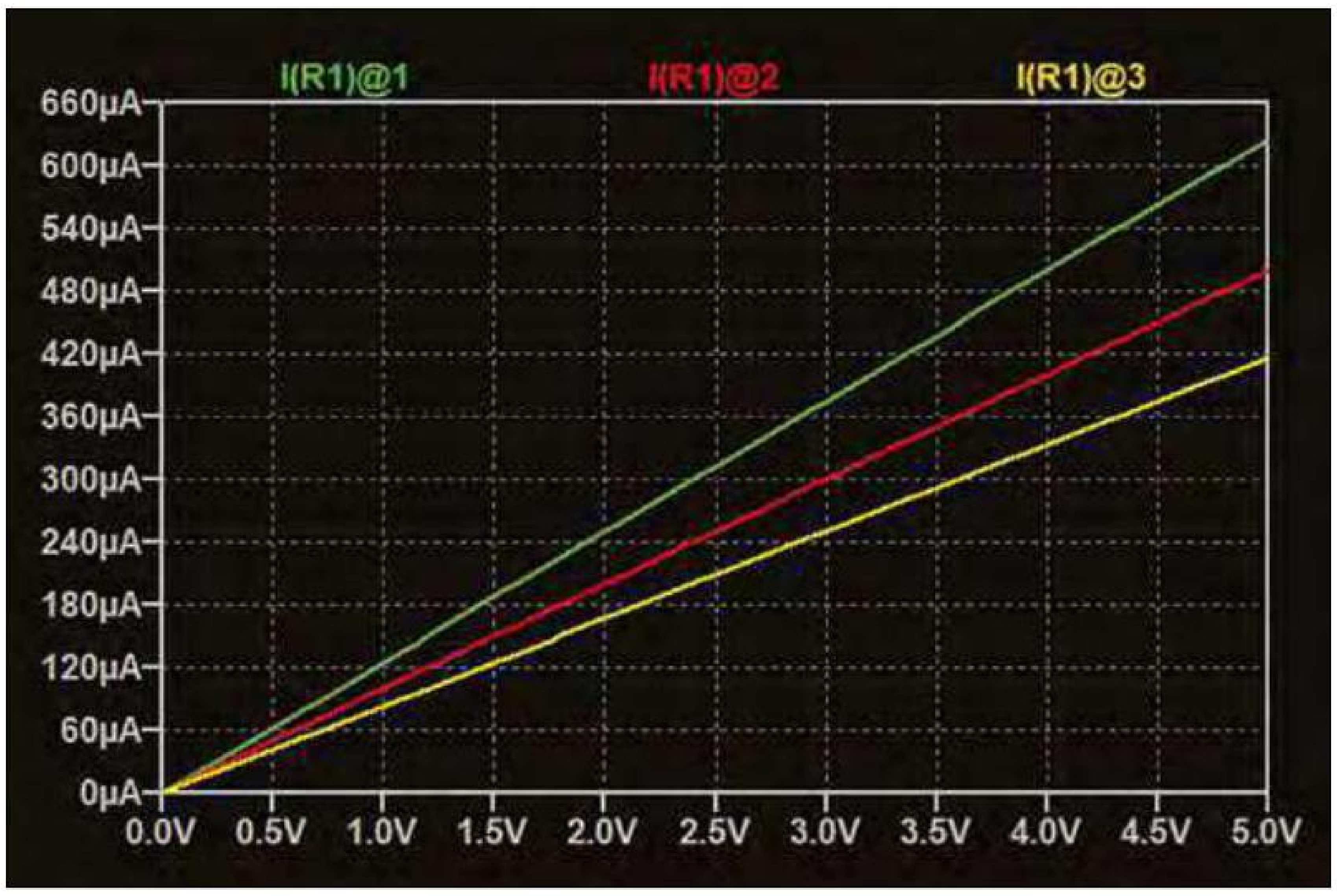


Fig.10. Plotting specific sweep step waveforms of the circuit in Fig.8.

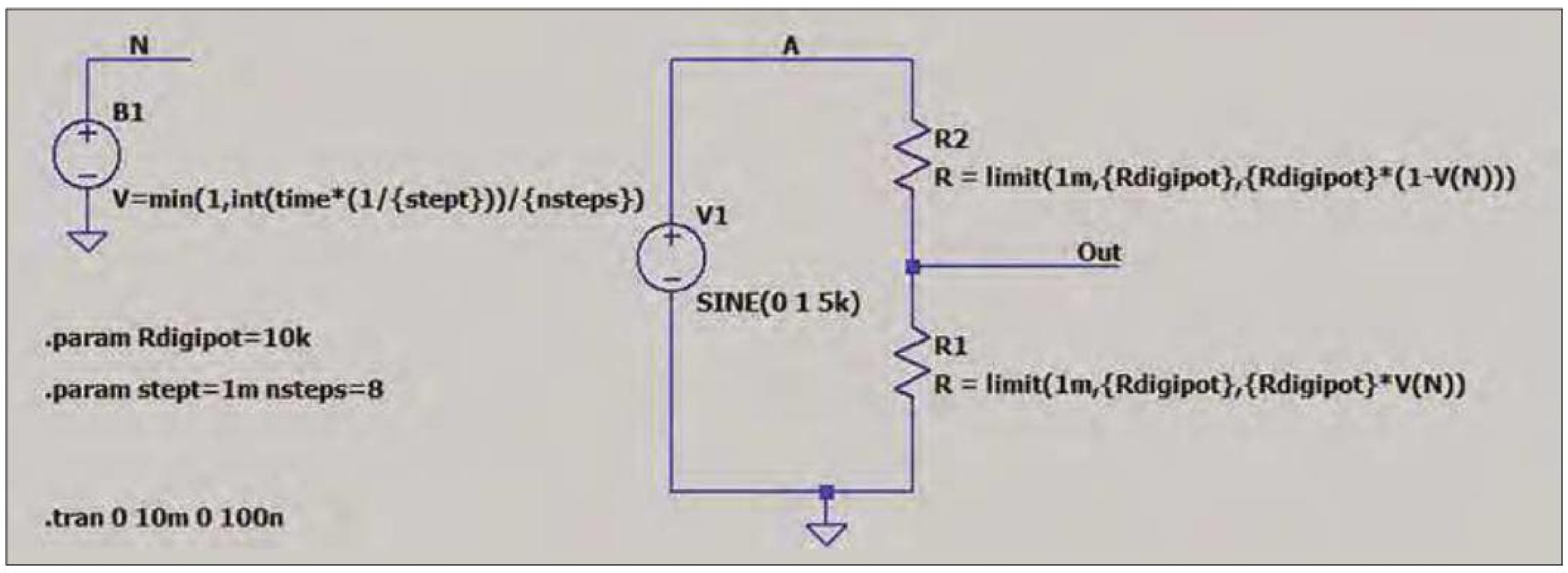

N
B1
V=min(1,int(time*(1/{stept}))/{nsteps})
A
R2
R = limit(1m,{Rdigipot},{Rdigipot}*(1-V(N)))
V1
Out
SINE(0 1 5k)
R1
R = limit(1m,{Rdigipot},{Rdigipot}*V(N))
.param Rdigipot=10k
.param stept=1m nsteps=8
.tran 0 10m 0 100n

Fig.11. Using LTspice behavioural resistors to implement a variable potential divider (digipot).

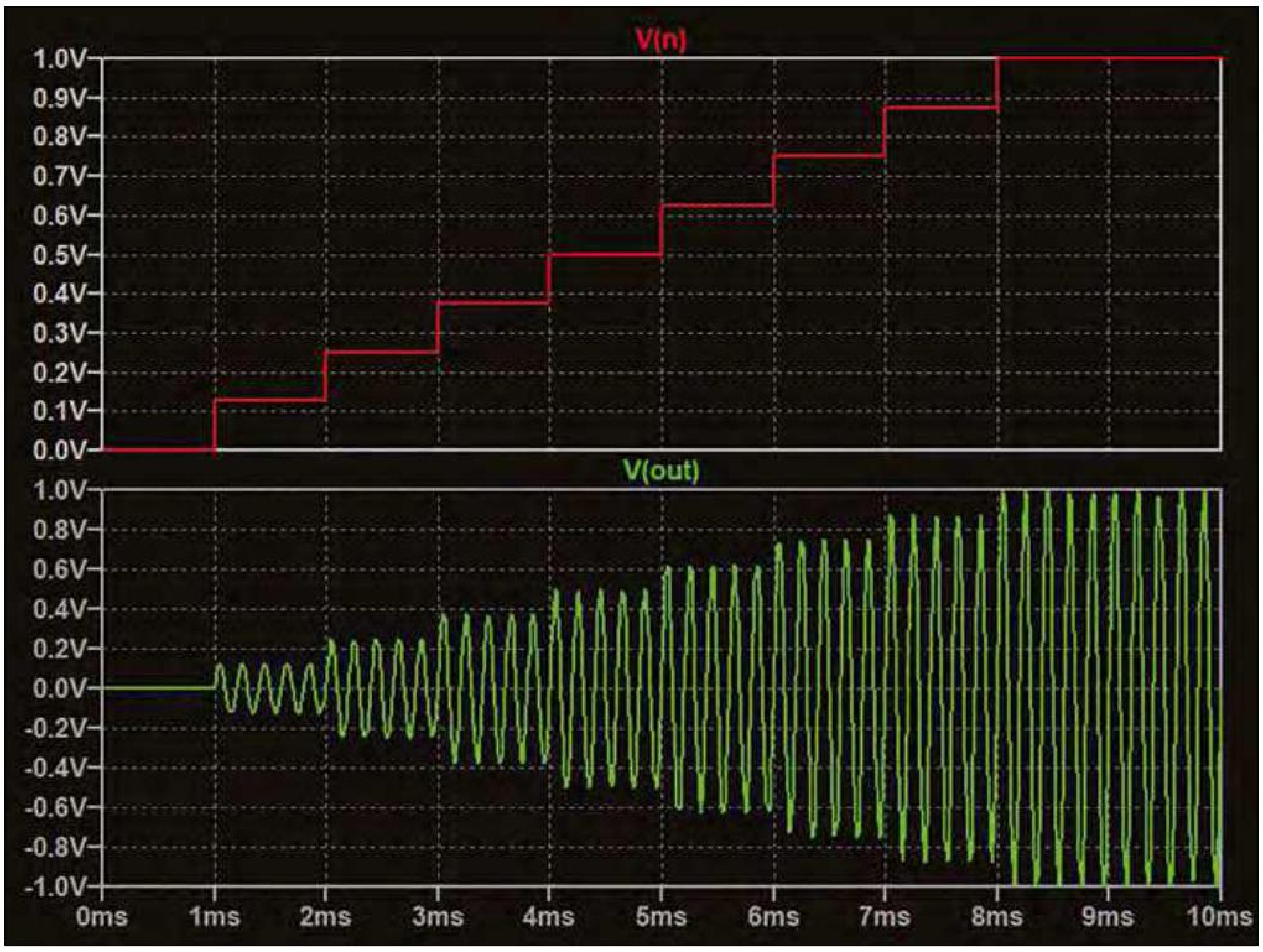


Fig.12. Results from simulation of the circuit in Fig.11.

these available under the 'Switches' section of the component selector in LTspice. The ADG1208 Low Capacitance, 8-Channel, ±15V/+12V iCMOS Multiplexer from Analogue Devices is close to the top of the list and is suitable to use in a variant of the circuit in Fig.3 because it has sufficient switches (we will use five of the eight). This is shown in Fig.6.

The ADG1208 simplifies the switch wiring and provides decoding of a binary value on its address inputs (`A0`, `A1` and `A2`). The simulation uses pulse voltage sources to control the address signals in a similar way to the circuit in Fig.3, but these are configured to produce a count in binary from 0 to 5 and are set to 3.3V for compatibility with the ADG1208 address inputs. The ADG1208 model also requires ±15V supplies (implemented using `V5` and `V6`). The ADG1208's `EN` (enable) pin must be connected to the positive supply to enable the switches. Like the circuit in Fig.3, this example applies a 1V 5kHz sinewave to the digipot potential divider.

The results of simulating the circuit in Fig.6 are shown in Fig.7. The binary count on the address bits (signals `n0`, `n1` and `n2`) can be seen together with the output voltage, which is similar to that in Fig.4 and Fig.5, except the amplitude is stepped in the opposite direction. This is because the switches in the circuit in Fig.6 are in the opposite order to what they should be – but it was convenient to drop the ADG1208 into the previous schematic this way round and is sufficient to show the principle of operation.

Use of the analogue multiplexer component models makes the digipot schematic easier to draw and facilitates use of digital codes. 16-channel multiplexer models are available (eg, ADG1206) and multiple chips could be used (by controlling their enable pins) to build larger switch networks. The disadvantage of this approach compared to the circuit in Fig.3 is that the characteristics of the switches are based on the multiplexer model and cannot be configured to match the characteristics of a different circuit implementation. The circuits in Fig.3 and Fig.7 both require a significant amount of drawing for digipots with larger numbers of switches, which would probably be impractical in most cases (eg, for 1024 taps).

The effects of tolerances

Before looking at other approaches to implementing digipots we will take a quick look at simulating component value variation. All components are subject to some variation or tolerance in individual values. Standard single resistors are readily available with relatively small tolerances (±1% or less) but the total resistance (R_{AB} in Fig.1 and Fig.2) of many digipots are subject to much larger tolerances, for example ±20% or more. This may cause difficulties in some situations, for example by restricting the range of values (eg, bias voltage or gain) that can be set up in a circuit.

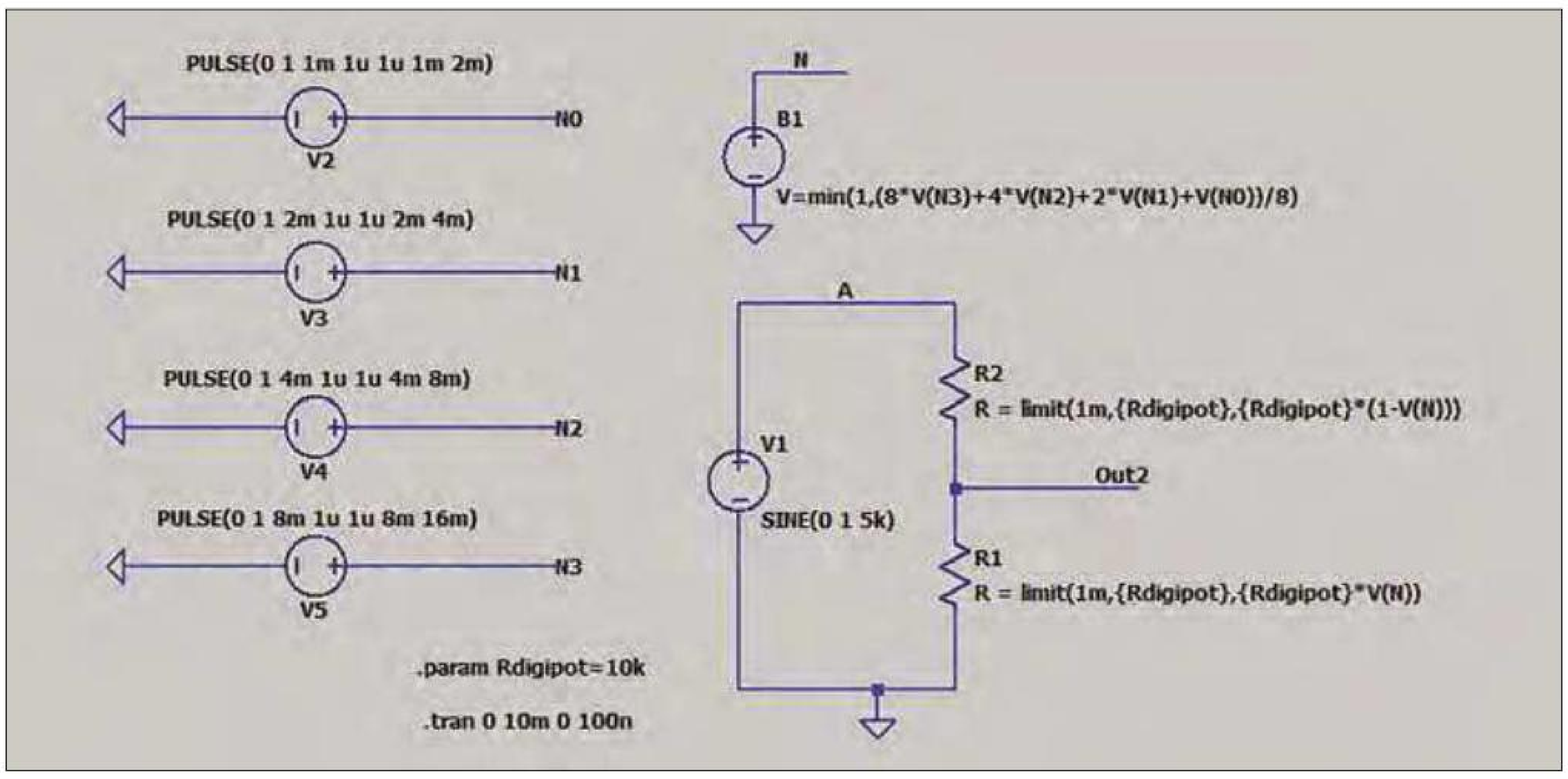

PULSE(0 1 1m 1u 1u 1m 2m)
N0
V2
PULSE(0 1 2m 1u 1u 2m 4m)
N1
V3
PULSE(0 1 4m 1u 1u 4m 8m)
N2
V4
PULSE(0 1 8m 1u 1u 8m 16m)
N3
V5
.param Rdigipot=10k
.tran 0 10m 0 100n
N
B1
V=min(1,(8*V(N3)+4*V(N2)+2*V(N1)+V(N0))/8)
A
R2
R = limit(1m,{Rdigipot},{Rdigipot}*(1-V(N)))
V1
Out2
SINE(0 1 5k)
R1
R = limit(1m,{Rdigipot},{Rdigipot}*V(N))

Fig.13. Variant of the circuit in Fig.11 with digital signals use to control wiper position.

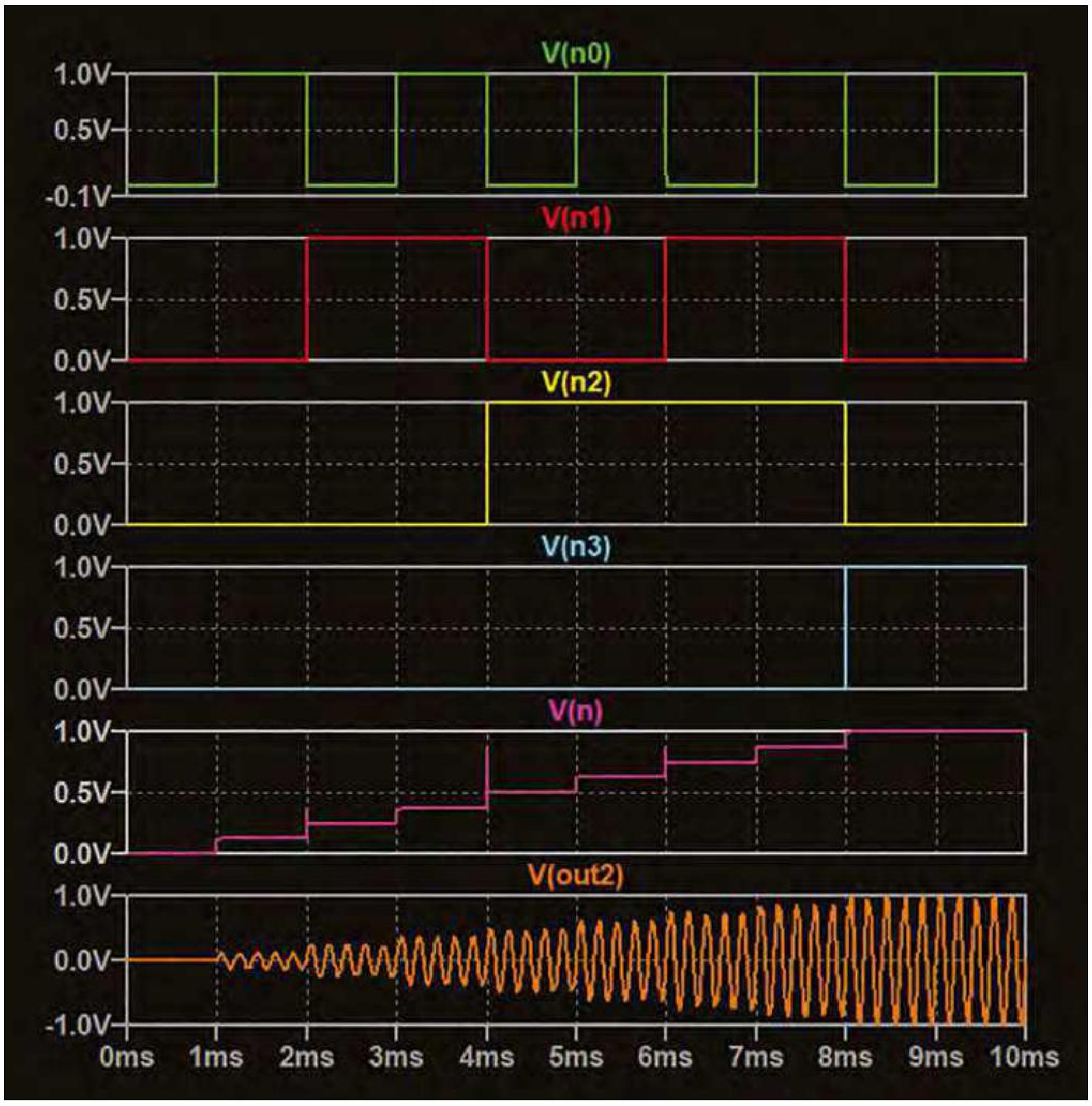


Fig.14. Results from simulation of the circuit in Fig.13.

Given that digipots are often controlled by embedded system software, the problem can be addressed by calibration routines in the code as long as the circuit is designed to be usable with the full range of possible digipot resistance values.

The circuit is Fig.8 shows one approach to simulating the effect of component value variation. It is simply a resistor with a DC voltage applied across it. We perform a DC sweep simulation, increasing the voltage from 0 to 5V and plot the current. To investigate the effect of resistor variation we could create separate copies of the circuit (on the same schematic) with different resistor values, or we could simply change values and run the simulation again. The first approach allows the different results to be plotted together, but results in a more complex overall schematic and it can be difficult to track which result is which. The second approach does not allow easy direct comparison of results.

Using a sweep command

LTspice provides the means to run multiple simulations of the same circuit with different component values using the `.sweep` command. There are a variety of ways of using `.sweep`, which are documented in the built-in Help. Here we define the resistor value using a parameter and use a parameter sweep to change the value. In LTspice, parameters can be defined using the `.param` command, after which they can be used in many places where you would ordinarily use a numerical value – for example, for the value of a resistor. In the circuit in Fig.8 the parameter `Rdigipot` is defined and given the value `10k` by the `.param` command:

```
.param Rdigipot=10k
```

The value of resistor `R1` is written as `{Rdigipot}` on the schematic – LTspice parameters are written inside curly braces when they are used. If we did not do anything else the simulation would simply use `10k` as the value of `R1`. However, in this case we also have the `.sweep` command:

```
.step param Rdigipot LIST 8k
10k 12k
```

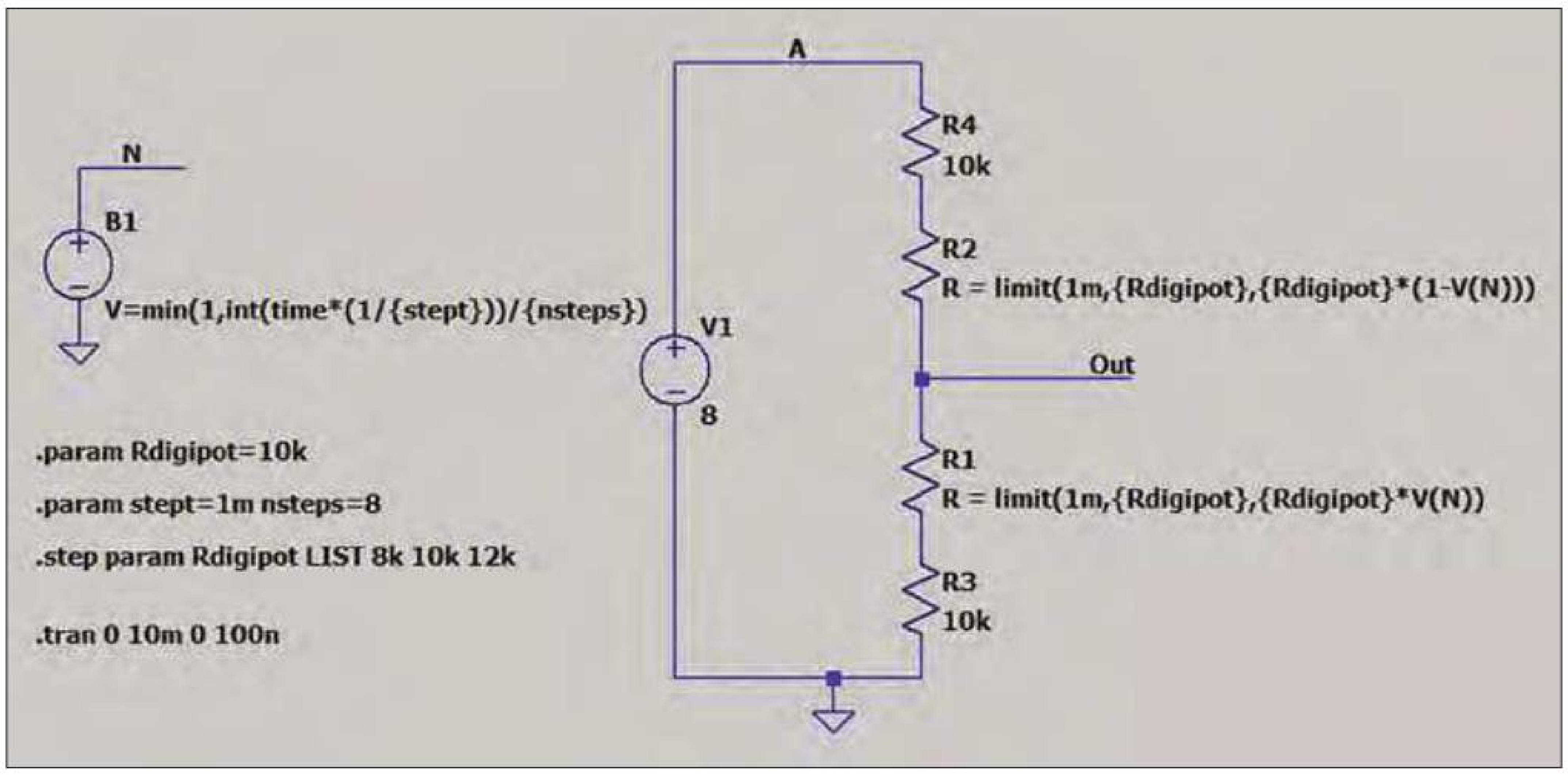
This tells LTspice to run the simulation multiple times with the set of values of `Rdigipot` as listed – here three values are used to represent the nominal value and extremes of a 10kΩ resistor with ±20% tolerance. This corresponds to a digipot with total resistance R_{AB} = 10kΩ and 20% tolerance.

The results of simulating the circuit in Fig.8 are shown in Fig.9. To identify the traces right-click on the schematic and select View -> Step Legend from the menu. You can also select which steps are displayed using View -> Select Steps. Individual step plots can be displayed by adding `@step_no` after the signal name, for example `I(R1)@1` to display the current in `R1` for step 1 of the sweep. This is illustrated Fig.10.

Model based on a potentiometer

As mentioned above, an alternative to a direct circuit implementation (as in Fig.3 and Fig.7) is to use a more abstract model based on a simple potentiometer. This requires that the resistor values can be controlled by mathematical expressions to relate the resistor values to the control input – fortunately, this is possible in LTspice using 'behavioural resistors'. We have used behavioural voltage and current sources (`BV` and `BI` elements) a number of times in previous *Circuit Surgery* articles. These sources allow the use of a mathematical expression to set the voltage or current – the expression can make use of other circuit voltages and currents and simulation time, and a wide range of mathematical functions are available for use. The resistance of a resistor (`R` element, as in a standard resistor) can also be set by an expression in similar way. This feature is not fully documented in LTspice – at the time of writing, if you look up 'resistor' in the built-in Help it is not mentioned. However, we can use behavioural resistors to implement a digipot function.

In general, a potentiometer comprises two resistors $R_1 + R_2$ such that the total resistance $R_1 + R_2 = R_{AB}$ where R_{AB} is


A
N
B1
V=min(1,int(time*(1/{stept}))/{nsteps})
V1
8
R4
10k
R2
R = limit(1m,{Rdigipot},{Rdigipot}*(1-V(N)))
Out
R1
R = limit(1m,{Rdigipot},{Rdigipot}*V(N))
R3
10k

```
.param Rdigipot=10k
.param stept=1m nsteps=8
.step param Rdigipot LIST 8k 10k 12k
.tran 0 10m 0 100n
```

Fig.15. Circuit to narrow digipot adjustment range. This simulation includes component tolerance.

the resistance between the terminals A and B (as in Fig.2). The relative values of R_1 and $R2$ depend on the wiper position. If we define the wiper position as a value N, where $N = 0$ with the wiper at B and $N = 1$ with the wiper at A then we can write if $R_1 = NR_{AB}$ and $R_2 = (1 - N)R_{AB}$. In LTspice we can set up a voltage on node `N`, `V(N)`, which can vary from 0 to 1V to represent N. We can define a parameter `Rdigipot` for the R_{AB} value of the digipot. Then we could use two behavioural resistors to implement a potentiometer with values set by expressions using:

```
R = {Rdigipot}*V(N)
R = {Rdigipot}*(1-V(N))
```

Things are a bit more complex than this because the behavioural resistor value must not be set to zero, and ideally not become negative. We can use the LTspice `limit(x,y,z)` function, which returns `z` unless it is outside the range set by `x` and `y`, in which case `x` or `y` are returned. Using this we can limit the minimum resistance to some very small value (eg, 1mΩ) and the maximum to the R_{AB} value (`Rdigipot`), for example:

```
R = limit(1m,{Rdigipot},{Rdigipot}*V(N))
```

An LTspice schematic using this approach is shown in Fig.11. The behavioural voltage source (`BI`) is used to create a stepped waveform on node `N`, starting at 0V at time 0 and stepping every step-time (`stept` parameter) by 1/(number of steps) (`nsteps` parameter) until a maximum of 1 is reached. The parameter values shown in Fig.11 step `V(N)` from 0 to 1V in 8 steps, with each step lasting 1ms. The results are shown in Fig.12 and show a similar behaviour to the previous examples. However, unlike the previous examples, it is easy to change the effective number of taps (switches) in the digipot. For example, for 256 switches set `nsteps` to 256 and the simulation end time to 256ms.

The circuit in Fig.13 is similar to the one in Fig.12 except the behavioural source producing `V(N)` is obtained from a set of signals (on nodes `N0` to `N3`) representing a 4-bit binary control word for the digipot. This provides a more realistic control input but requires the additional sources to generate the digital control signals. The `B1` source uses a weighted sum of the digital bits (which are at 0V or 1V for logic 0 and 1) to produce the control voltage `V(N)`. The results are shown in Fig.14 and are as expected. There are some glitches on `V(N)` caused by the relative switching times of the digital signals

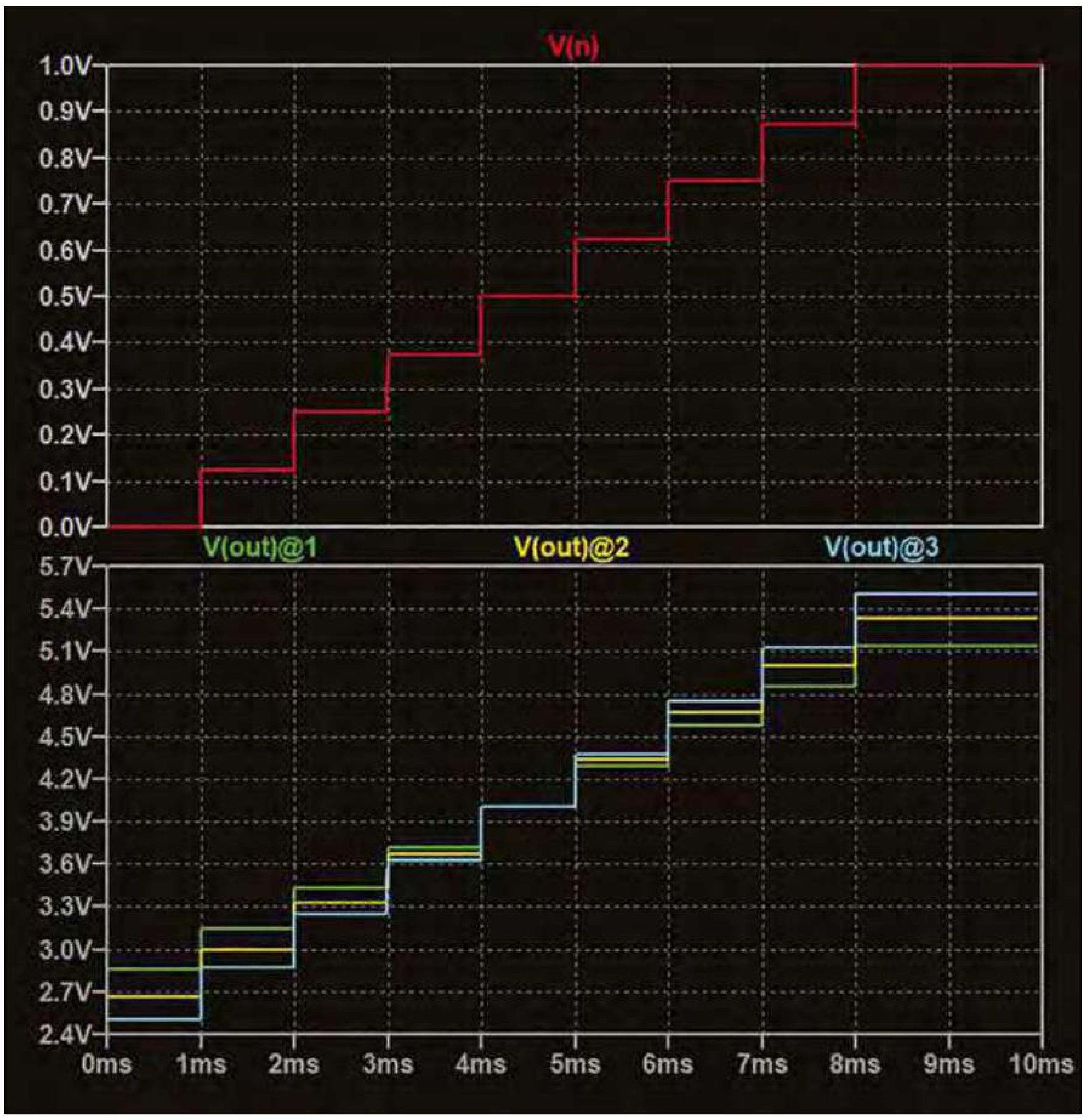
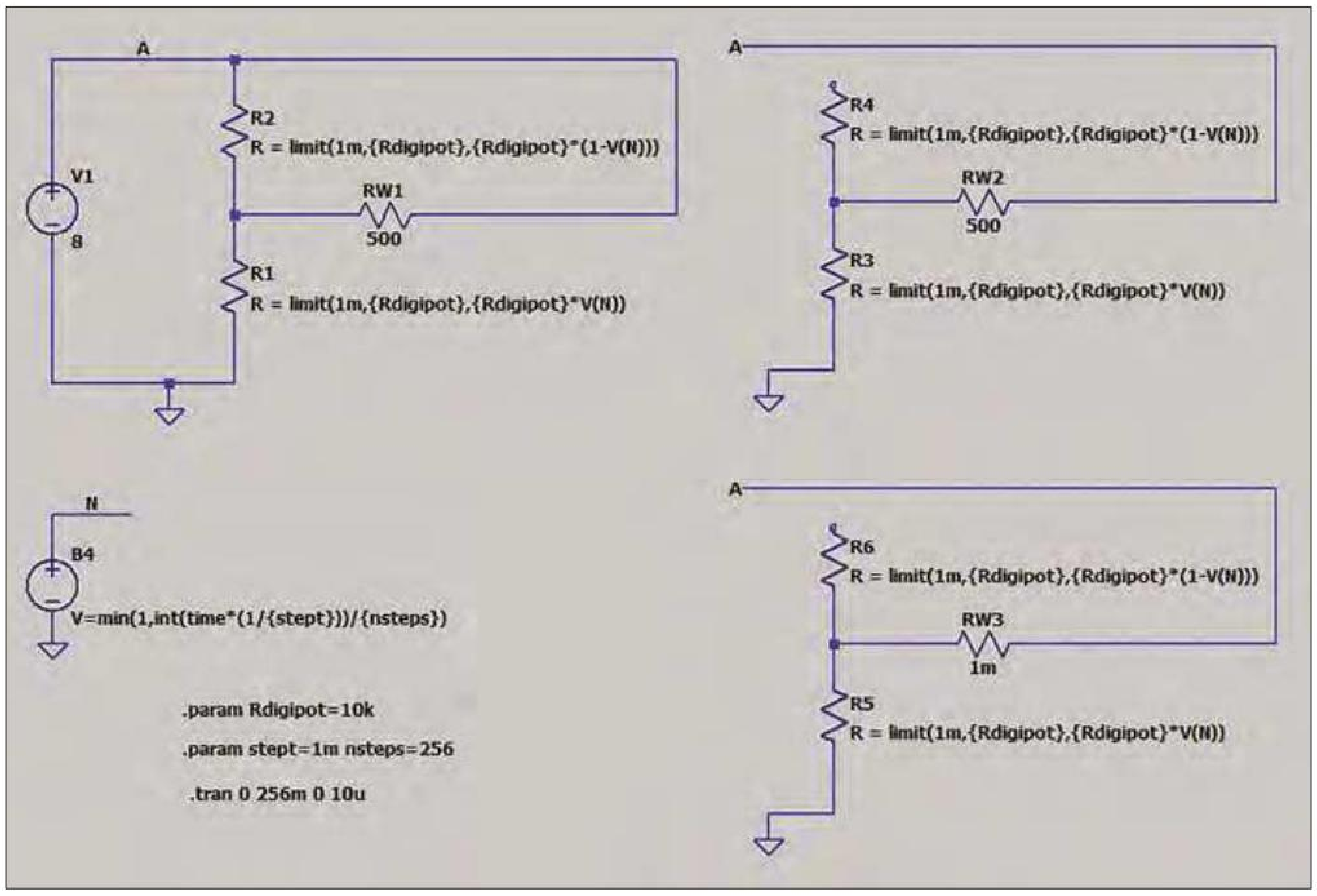


Fig.16. Results from simulation of the circuit in Fig.15.


A
R2
R = limit(1m,{Rdigipot},{Rdigipot}*(1-V(N)))
V1
8
RW1
500
R1
R = limit(1m,{Rdigipot},{Rdigipot}*V(N))
A
R4
R = limit(1m,{Rdigipot},{Rdigipot}*(1-V(N)))
RW2
500
R3
R = limit(1m,{Rdigipot},{Rdigipot}*V(N))
N
B4
V=min(1,int(time*(1/{stept}))/{nsteps})
A
R6
R = limit(1m,{Rdigipot},{Rdigipot}*(1-V(N)))
RW3
1m
R5
R = limit(1m,{Rdigipot},{Rdigipot}*V(N))

```
.param Rdigipot=10k
.param stept=1m nsteps=256
.tran 0 256m 0 10u
```

Fig.17. LTspice circuit to investigate the effect of wiper resistance when using rheostat mode.

Simulation files

Most, but not every month, LTSpice is used to support descriptions and analysis in *Circuit Surgery*.
The examples and files are available for download from the *PE* website.

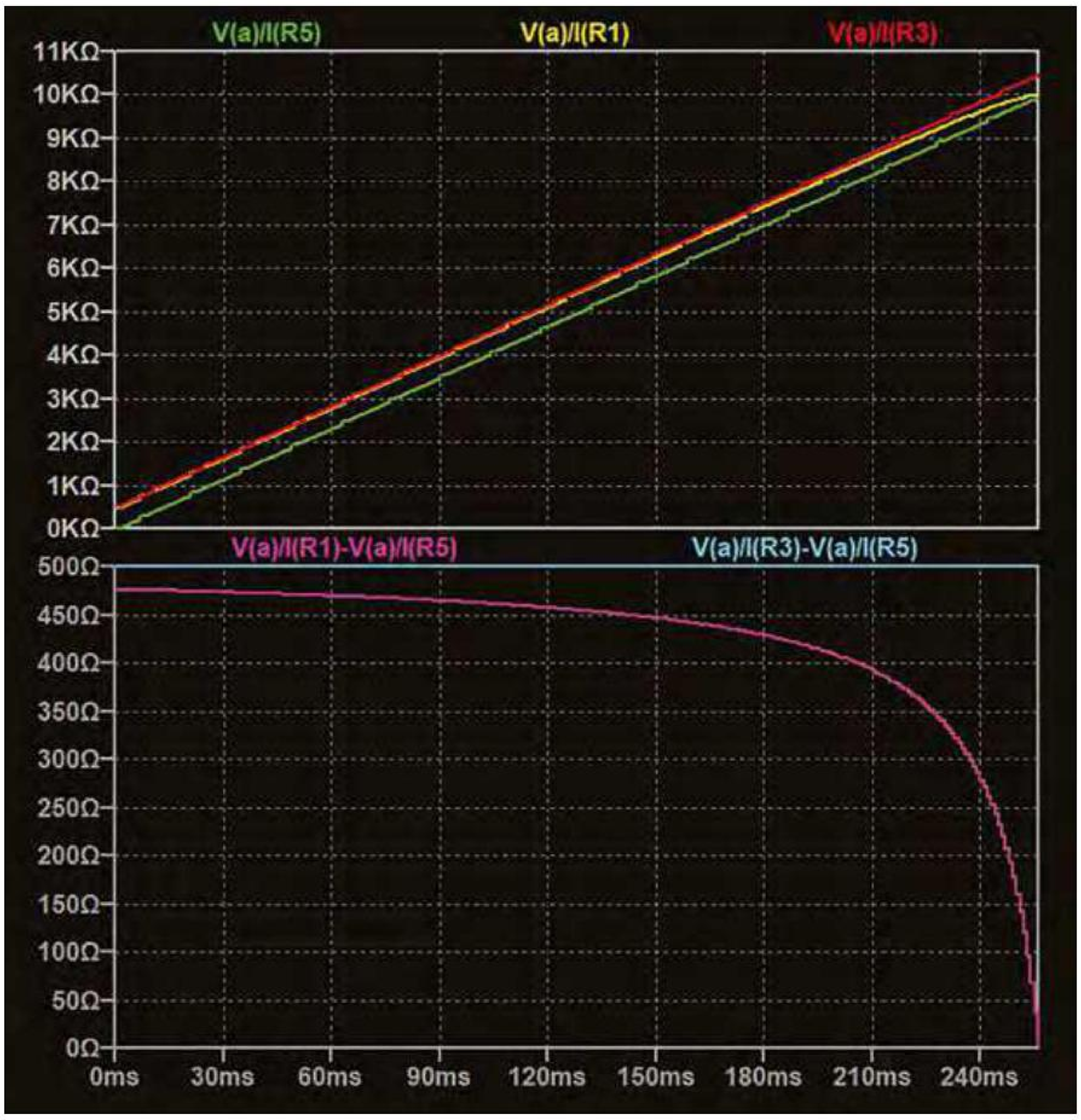


Fig.18. Results from simulation of the circuit in Fig.17.

which could be fixed by refining the timing.

Fig.15 shows a circuit in which the digipot is placed between two fixed resistors. This technique narrows the proportion of the potential divider output which is controlled by the digipot – it is not unusual to require an adjustment range significantly smaller than 0 to 100% of the input (as provided by the circuit in Fig.11). For a given number of taps (wiper steps) this increases the resolution with which the output can be controlled. This simulation is run with value variation for the digipot of ±20% for a nominal value of 10kΩ using the approach discussed earlier. The input is simply 8V DC so the output will be a DC value as set by the potential divider formed by the four resistors.

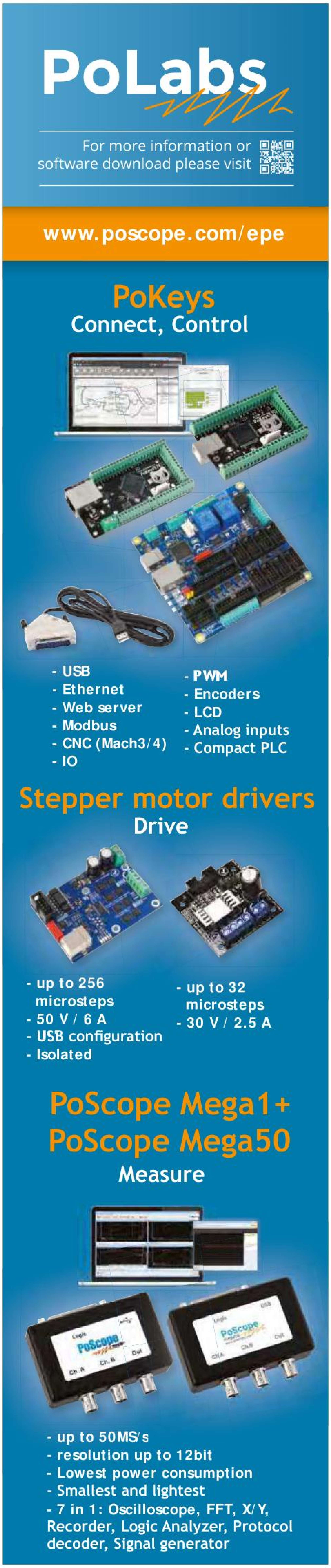
Digipot resistance variation

The results are shown in Fig.16. Here we can see that the variation in digipot resistance results in a variation in the range of output voltages that can be set. This is potentially a major problem – if the circuit was designed to utilise the full control range available with the nominal 10kΩ resistance, individual digipots with smaller resistance would not be able to control the full range of output levels. The design should be based on the worst case (in this case 8kΩ gives the smallest control range – green trace for `V(out)@1`). Another problem here is that different control inputs give different output levels with different digipot resistance values. This could be accounted for using calibration procedures in software. For example, if the individual digipot resistance value was known and stored in non-volatile memory, then microcontroller software could use the value in calculations to set the required control value.

Wiper resistance

Previously, we mentioned that digipots have a wiper resistance – this can affect the performance of circuits. For example, if a digipot is used in rheostat mode (single variable resistor) the wiper resistance will contribute to the total resistance. Fig.17 shows three circuits using a digipot in rheostat mode. The top two circuits have a relatively large wiper resistance (500Ω) to show its effect and the lower circuit has minimal wiper resistance (1mΩ) as a reference for comparison. In rheostat mode, one terminal of the potentiometer is not used – it can either be shorted to the wiper (top left in Fig.17) or left disconnected (top right).

The results in Fig.18 show that the two spare terminal options produce different behaviours. The top pane plots the resistance of all three rheostats against time as the control input is stepped from 0 to 1 (zero to maximum resistance in 256 steps). The reference rheostat (green trace) has the lowest total resistance, and the others are larger due to the wiper resistance being included in the total value. The lower pane shows the difference between the reference value and the top two circuits. The circuit with the disconnected spare terminal has a constant difference equal to the wiper resistance. The circuit with the shorted spare terminal has a lower difference (is closer to the ideal value) but the difference varies with wiper position, which would make it more difficult to account for the wiper resistance in software calibration.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- LCD
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- Compact PLC
Stepper motor drivers
Drive
- up to 256 microsteps
- 50 V / 6 A
- USB configuration
- Isolated
- up to 32 microsteps
- 30 V / 2.5 A
PoScope Mega1+
PoScope Mega50
Measure
- up to 50MS/s
- resolution up to 12bit
- Lowest power consumption
- Smallest and lightest
- 7 in 1: Oscilloscope, FFT, X/Y, Recorder, Logic Analyzer, Protocol decoder, Signal generator

Max's Cool Beans

By Max the Magnificent

Arduino Bootcamp – Part 1

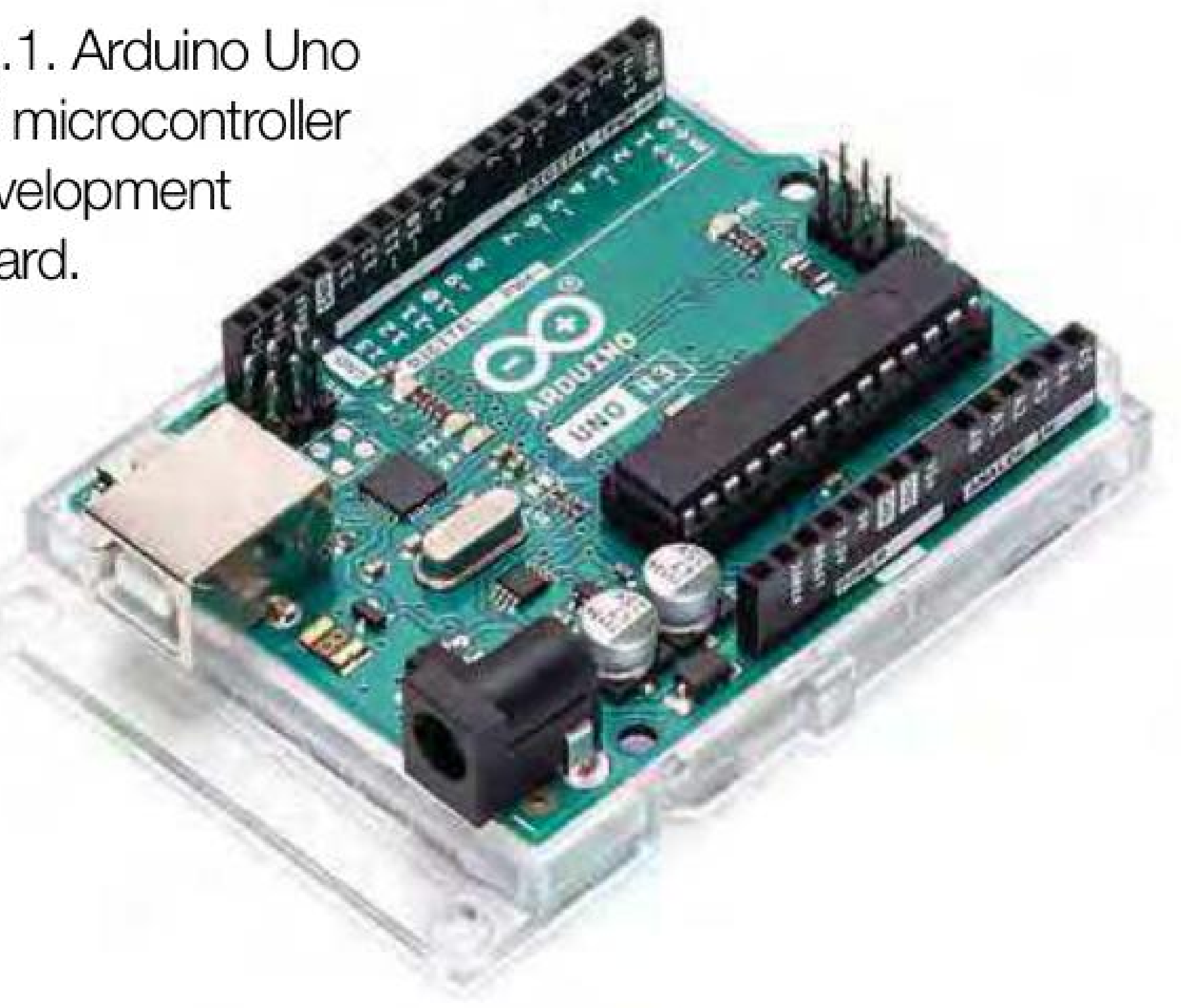


Fig.1. Arduino Uno R3 microcontroller development board.

As I happily meander (some may say 'blunder') my way through life, I meet a lot of people with ages ranging from youthful sprogs to venerable golden-agers who are interested in learning about computers in the form of microcontrollers.

These people come from all walks of life. A few years ago, for example, I was introduced to an ex-army attack helicopter pilot whom we'll call Mike (because that's his name). Mike was in the process of building a gigantic model railway. He wanted to be able to illuminate the streetlights and houselights in his miniature world, but he didn't want them to all simply turn on and off at the same time. Mike's wish was that when he dimmed the lights in the room housing the layout, the streets in his model would light up at slightly different times. Also, that the lights in the houses would start to turn on in a random fashion. This was, of course, a perfect task for a microcontroller, so I gave Mike a crash course and helped him get things up and running.

There are vast amounts of training resources already available for this sort of thing in the form of books, websites and YouTube videos, but sometimes it can be hard to take that first trepidatious step (don't worry, I'm right behind you and I'll be happy to give you a push).

It's also true that there are many ways into this topic, and everyone teaches things differently, so if you've already tried dipping your toes in the microcontroller waters, only to find them cold, confusing and uninviting, perhaps I can persuade you to try once more with your humble narrator as your guide (I pride myself on my humility).

Meet the micro

You've probably heard the terms microprocessor and microcontroller. These are often abbreviated to MPU (for microprocessor unit) and MCU (for microcontroller unit), respectively. So, what's the difference?

Well, a high-level way of looking at this is as follows. The brain of a digital computer is its central processing unit (CPU), which is where all the number crunching and decision making takes place. An MPU is essentially an integrated circuit (IC) – also known as a silicon chip – containing only a CPU, with everything else (eg, memory and peripheral functions) being presented externally as separate devices. By comparison, in addition to its CPU, an MCU also contains on-chip memory and on-chip peripheral functions.

The MCU's on-chip memory comes in two main forms: Flash and RAM. The Flash is non-volatile, which means it retains its contents when power is removed from the system. In turn, this means we can store a program in the Flash memory and, when power is applied to the system, the MCU will wake up and immediately start to execute that program. By comparison, the RAM, which stands for 'random-access memory', is volatile, which means it forgets its contents when power is removed from the system. When the MCU is running, the RAM is used by the program to store temporary values, intermediate results from any calculations, and data read from the outside world.

The microcontroller with which we will be playing is an ATmega328P. This device was originally created by a company called Atmel, which was acquired by another company called Microchip Technology in 2016.

A microcontroller development board is a printed circuit board (PCB) that contains a microcontroller along with other devices and connectors. The microcontroller development board we will be using for our experiments is an Arduino Uno R3 (Fig.1) (the ATmega328P is the big 28-pin chip presented in a dual in-line (DIL) package that's located in the middle-ish of the board).

You can find these little rascals all over the place (like Amazon, for example: **https://amzn.to/3TFkltu**). When you are making your purchase, check that your Arduino Uno comes with an associated USB cable, otherwise make sure that you have a USB-A to USB-B cable lying around (the A end plugs into your host computer while the B end plugs into the Arduino).

What a shock

Call me an old fuddy-duddy if you wish, but I've been the victim of electrostatic discharge (ESD) more times than I care to remember, so I strongly recommend that you take appropriate anti-static precautions.

Is this mandatory? No. Is it a good idea? Yes. Suppose you are ambling your way around your home after making a refreshing cup of tea, and you build up an electrostatic charge on your way. (For modelling the effect of ESD on sensitive electronic devices, a human being is represented as a capacitor of 100pF (picofarads) charged to a voltage of up to 35kV (35,000 volts). Suffice it to say, it can be a monumental pain if you zap yourself. It can also make your eyes water if you end up destroying one of the elements – a pin on your nice new Arduino, for example – of a project on which you've been working for hours, before you've even had a chance to play with it.

To prevent any such unfortunate occurrence, may I make so bold as to suggest that you invest in an anti-static mat (**https://amzn.to/3g1YH4A**) and an anti-static wrist strap (**https://amzn.to/3WYZ9Bu**). Both typically come with crocodile clips (a.k.a. 'alligator clips' in the US), which you can pull off to reveal banana plugs. My preferred *modus operandi* is to plug these banana plugs into an anti-static grounding plug (**https://amzn.to/3hDIcML**), which is – in turn – plugged into a wall socket or a power strip. To be clear, the connection is just to ground – *never* to the bitey terminals (live/active or neutral)!

Let's get started

An Arduino Uno (Fig.2) requires 5V to perform its magic. One possibility is to use a 9V supply plugged into the Arduino's

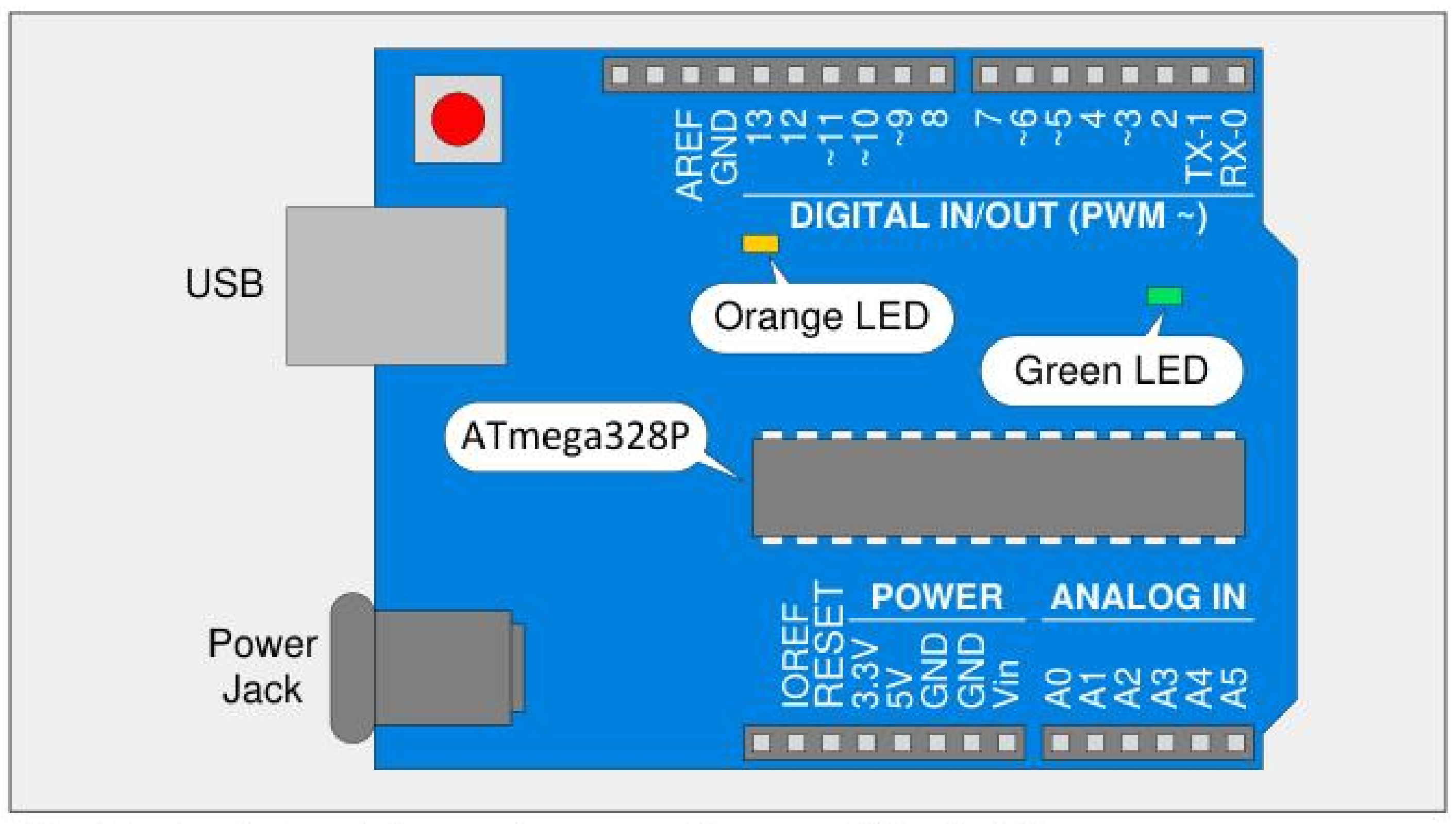


Fig.2. Arduino Uno pins and two of its LEDs.

power jack, in which case the Uno's primary on-board regulator will drop this down to the desired 5V. For the purposes of our initial experiments, however, we are going to supply power via the Uno's USB port, with the other end of the cable being plugged into our host computer (Windows, Mac or Linux). In addition to being used to download programs into the Arduino, this cable (well, the host computer) also supplies up to 500mA of current at the required 5V.

This is a good time to note that various external sensors and other components we might one day wish to connect to our Arduino Uno may require either 5V or 3.3V. Thus, the Uno has a secondary on-board voltage regulator that takes the 5V supply and drops it down to 3.3V. Note the header (connector) marked 'POWER' on the bottom of Fig.2. This is one way in which we can access 5V and 3.3V sources to power our external devices.

Now, take your USB cable, plug the A end into a port on your host computer and plug the B end into your Arduino Uno. The first thing you should observe is that the green LED on the Uno starts to glow continuously to tell you that power is being supplied to the board. If you don't see this LED light up, then check that your computer is powered on and that your USB cable is plugged in all the way at both ends. If the LED still doesn't light, we might need to consider the possibility that you have a broken cable or a non-functioning Uno (or a non-functioning green LED).

Assuming the green LED does light up and this is a brand new Arduino Uno, then the second thing you should observe is that the orange LED starts to slowly flash, turning on for one second and then off for one second and then repeating this cycle over and over again.

The reason for the orange LED flashing is that, by default, every Arduino Uno is loaded with a sample program called *Blink* before it's delivered to the end user, which is you, where the sole purpose of the *Blink* program is to flash the orange LED.

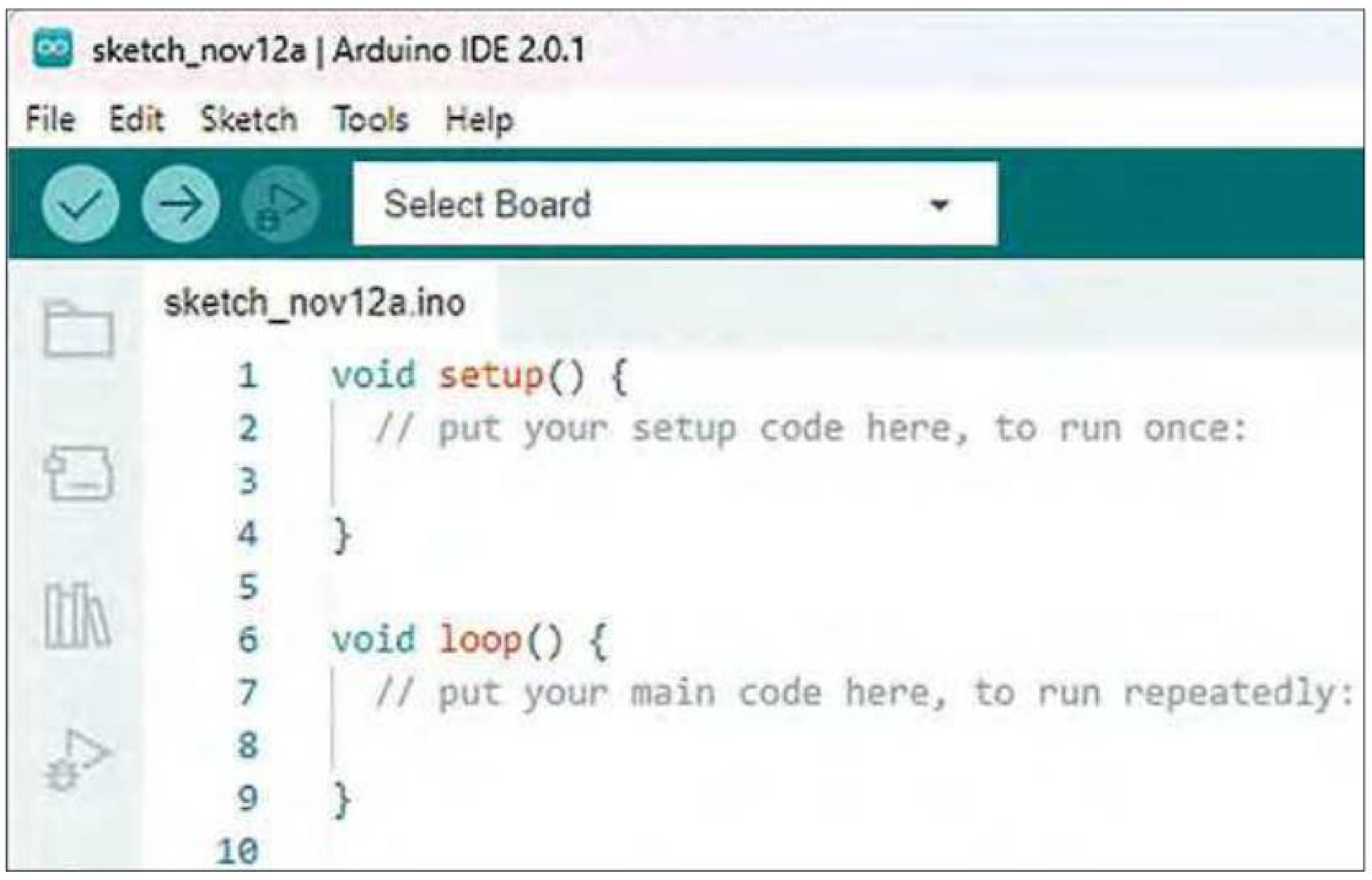
Meet and greet the IDE

In a moment we are going to create our own version of the *Blink* program (Arduino aficionados typically use the term 'sketch' as an alternative to saying 'program'). To do this, we need something called an integrated development environment (IDE), which is a software application that runs on our host computer.

The Arduino IDE provides a suite of tools and capabilities, like a source code editor, a compiler, a debugger, and the ability to upload our programs into our Arduino. To access the IDE, visit the **Arduino.cc** website and click on the SOFTWARE tab. There are two versions of the IDE – the original IDE 1 and the more recent IDE 2 – we will be working with IDE 2, so this is the one you should download and install.

Once you've installed the IDE, connect your Arduino Uno to your host computer and launch the IDE (it doesn't matter in which order you perform these two tasks). Observe the upper left-hand corner of the IDE window (Fig.3).

Note the field containing the 'Select Board' text. Click the down-pointing arrow at the right-hand side of this field and select the entry reflecting your Arduino Uno and the COM port to which it is connected (alternatively, use the Tools > Board menu to select the Arduino Uno and the Tools > Port menu to select the COM port).



```
void setup() {
  // put your setup code here, to run once:

}

void loop() {
  // put your main code here, to run repeatedly:

}
```

Fig.3. Our first look at the Arduino IDE.

Creating our first program

As we see, the IDE has already started to create a program (sketch) for us. There are many more computer programming languages roaming wild and free in the cybersphere than you might suppose. If you visit the 'List of programming languages' page on the Wikipedia (**https://bit.ly/3NZMQ3N**), I think you'll be surprised (the words 'astonished' and 'alarmed' may also apply).

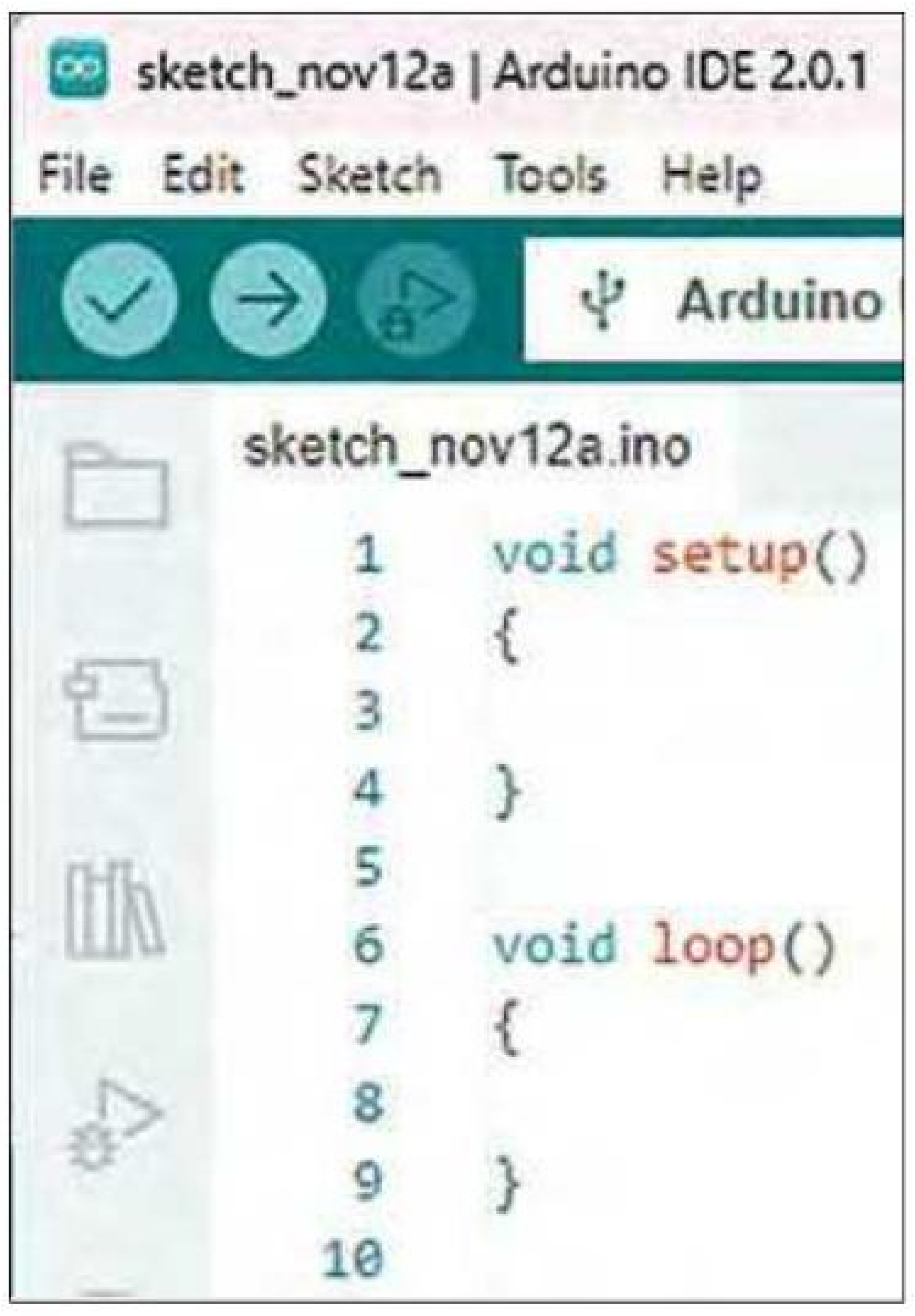
Two of these languages are called C and C++. (We can think of C++ as being a superset of C, although this isn't strictly true.) Arduino programs are written in C/C++. There are many resources available to you to learn these languages, one of which will be this series of *Arduino Bootcamp* columns.

Every Arduino program includes two functions called `setup()` and `loop()`. The `setup()` function is executed only once at the beginning of the program, after which the `loop()` function is executed over and over again.

The body of each function is bounded by open '{' and close '}' squiggly brackets – their official name is 'braces' (smooth curved versions – ( ) – are called 'parentheses', while square ones – [ ] – are 'brackets'). Anything following a pair of // characters is seen by the IDE as a comment (for humans) and is ignored (by the program). The first thing I always do is remove the IDE-generated comments. The second thing I do is move the squiggly open brackets so that they are vertically aligned with their squiggly close bracket counterparts (Fig.4).

We should probably note that C/C++ are free-form languages, which means the positioning of characters on the page in the program text is insignificant. However, experience has taught me that it's a lot easier to understand and debug programs when matching pairs of squiggly brackets are vertically aligned.

Now let's create our program, as shown in Fig.5, and use the File > Save As command to save it with the name *MyBlink*. The Arduino IDE includes a predefined suite of easy-to-use functions. We are employing three of these functions in our program: `pinMode()`, `digitalWrite()`, and `delay()`.

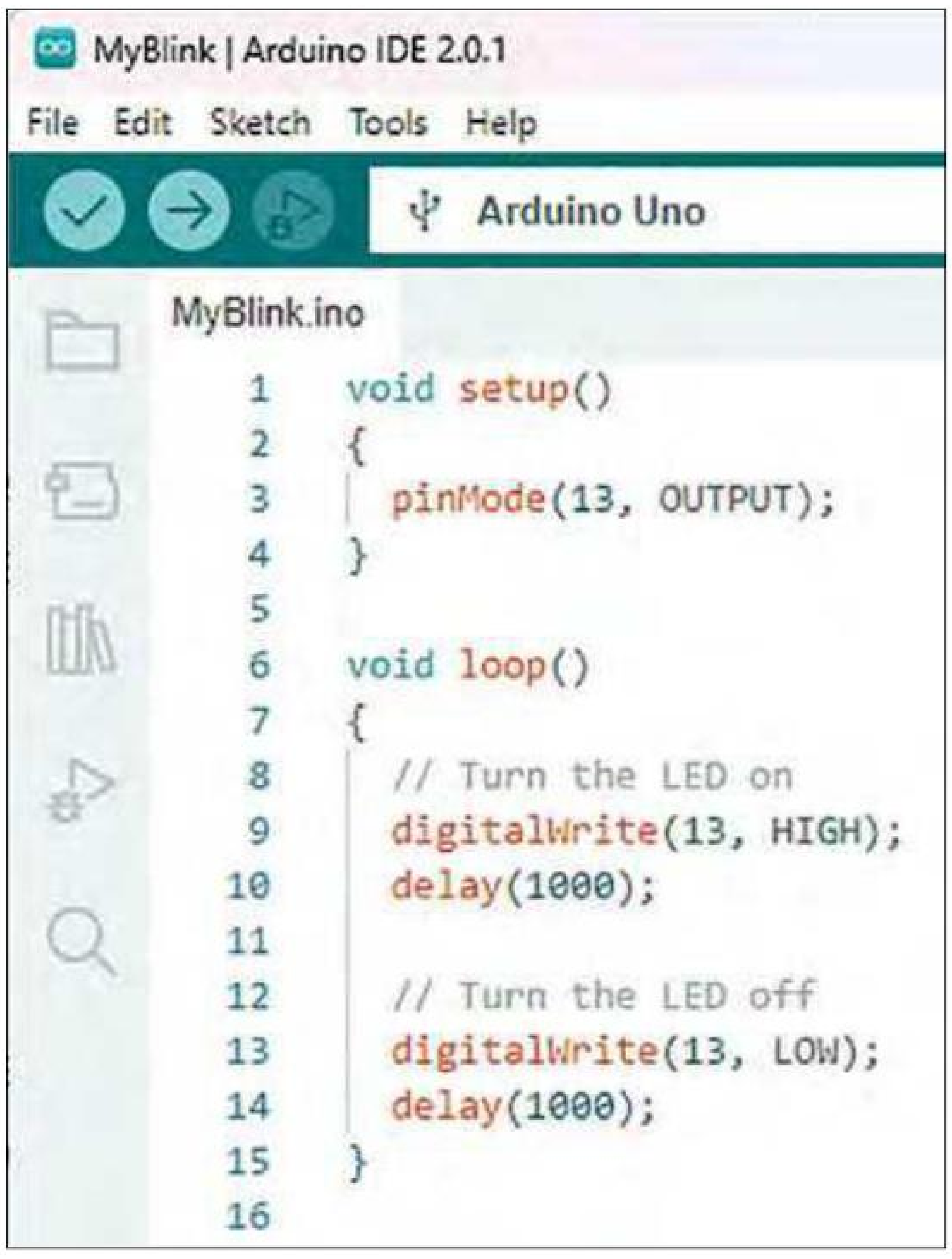


```
void setup()
{

}

void loop()
{

}
```

Fig.4. Let's get organised!

The digital pins on a microcontroller can act as both inputs and outputs, which is why we call them input/output (I/O) pins. When a microcontroller is first powered up, before its program starts to execute, on the principle of *primum non nocere*, which is Latin for 'first, do no harm,' all of its pins are set to be inputs by default.

The `pinMode()` function is used to configure a specified pin as being an input or



```
void setup()
{
  pinMode(13, OUTPUT);
}

void loop()
{
  // Turn the LED on
  digitalWrite(13, HIGH);
  delay(1000);

  // Turn the LED off
  digitalWrite(13, LOW);
  delay(1000);
}
```

Fig.5. Our first version of our own *Blink* program.

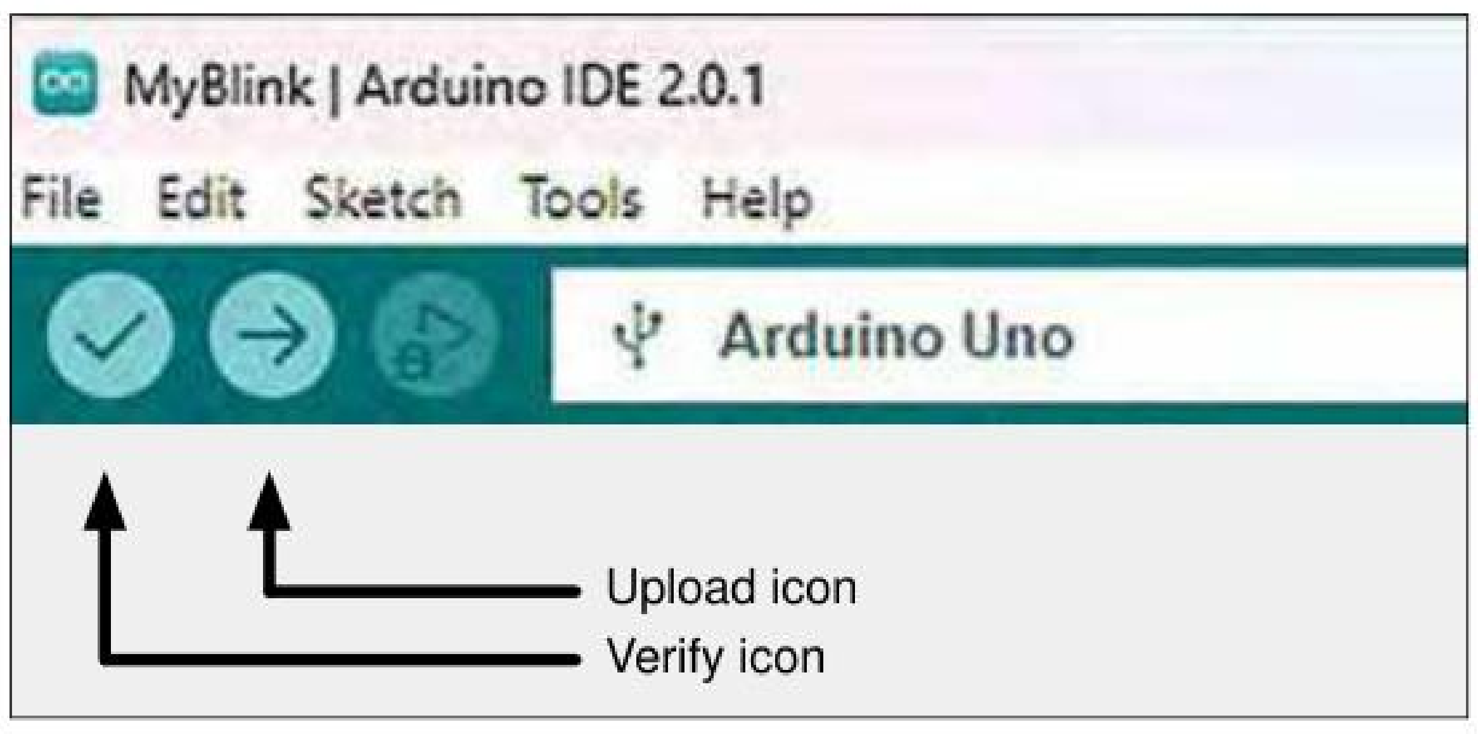


Fig.6. The Verify and Upload icons.

an output. This function accepts two 'arguments' (parameter values in computer speak). The first is the number of the pin in which we are interested. The second is a keyword (`INPUT` or `OUTPUT`), which specifies the mode. In this program, we are declaring digital pin 13 as being of type `OUTPUT`. The reason this statement is in the `setup()` function is because we only need do it once.

Just to be sure we're all tap dancing to the same skirl of the bagpipes, digital pin number 13 on the ATmega328P is connected to the pin marked 13 on the DIGITAL IN/OUT header on the Arduino Uno development board (Fig.2). Also, it's connected to the orange LED on the board.

The `digitalWrite()` function is used to write a value to a specified digital pin, where this value will be presented to the outside world. This function accepts two arguments. The first is the pin number in which we are interested. The second is the value we wish to present to the outside world. In this example, we are using the keywords `LOW` and `HIGH`, which – for the moment (and with respect to our on-board orange LED) – we can consider as representing the states Off and On, respectively.

Last, but not least, the `delay()` function pauses the execution of the program. This function accepts only one argument – the amount of time the program will pause – specified in milliseconds (ms), where there are 1000ms in a second.

To summarise the contents of our current `loop()` function: we turn the orange LED on and wait for one second, then we turn the LED off and wait for one second. Remember that, in the Arduino world, the `loop()` function is automatically called over and over again, so this will result in the continuous flashing of our orange LED.

Compiling and uploading

In computing, the term 'compiler' refers to a computer program that compiles (translates) computer code written in one programming language (the source language) into another language. In our case, the Arduino IDE's compiler translates our C/C++ source code into the machine code that will be executed by the Arduino Uno's microcontroller.

Let's start by verifying our code is good by clicking the Verify icon (Fig.6). We can also use the Sketch > Verify/Compile command. Hopefully, we will be presented with little popup windows saying, 'Compiling sketch' and 'Done compiling' accompanied by a report saying 'Sketch uses 924 bytes (2%) of program storage space' along with some other stuff. Alternatively, if we've done something wrong, we will be presented with a popup window saying 'Compilation error' accompanied by a report detailing any errors.

If the IDE informs you that you have errors and you can't work out what the problem is, then bounce over to the *Things to note* section a little later in this column. If you still have problems with your own version and simply can't resolve them, then download my version (file **CB-Jan23-01.txt**) from the January 2023 page of the *PE* website: **https://bit.ly/pe-downloads**

Let's assume there are no errors. In this case, we are ready to upload our program into the Arduino. We do this by clicking the Upload icon (Fig.6). We can also use the Sketch > Upload command. This time we should see a series of popup windows saying, 'Compiling sketch,' 'Done compiling,' 'Uploading,' and 'Done Uploading.' Also, during the upload portion of the process, two more LEDs marked TX ('transmit') and RX ('receive') located close to the orange LED on the Uno will flash to indicate that the upload is taking place.

Tweaking

Unfortunately, since all we've done is replicate the program that was already running in our Arduino, nothing will appear to have changed.

Let's try tweaking the LED's On and Off times. For example, set the On time to 100ms and the Off time to 900ms, and then click the Upload icon again. Observe that the orange LED now displays a 100ms (1/10th of a second) flash once a second.

Suppose we wish the LED to give two 100ms flashes separated by 100ms, and we want this to happen once every two seconds, can you modify your program to achieve this? If you are unsure, you can sneak a peek at my solution (file **CB-Jan23-02.txt**).

Things to note

There are a couple of things that are worth noting at this point. The first is that C/C++ are case-sensitive languages, which means uppercase and lowercase letters are treated as being distinct entities. Thus, `fred`, `Fred` and `FRED` would be seen as being three totally different things by the C/C++ compiler. Try changing one of our `delay()` function calls to `Delay()`, click the Verify icon, and see what happens (remember to change it back again afterwards).

Also, every statement in our program (which would be our function calls in this example) must be terminated by a semicolon ';' character. Try removing one of the semicolons associated with a statement in our `loop()` function, click the Verify icon, and see what happens (don't forget to add the semicolon back in again afterwards).

Break out a breadboard

A solderless breadboard (or 'breadboard' for short) allows us to create circuits without the need for soldering. The reason for the 'solderless' qualifier is that hobbyists of yesteryear (prior to 1971 when the solderless breadboard was invented) often created their circuits by hammering nails into pieces of wood and then wrapping their component leads and wires around these nails. Much to the chagrin of a youthful experimenter's parents, this piece of wood was oftentimes the same board upon which members of the family sliced their loaves of bread.

Breadboards come in several sizes. If you happen to have a half-size board, then this will suffice for the purposes of this column. Otherwise, I recommend you purchase a full-size board to accommodate our future columns. Actually, I just found a really good deal involving three full-size and two half-size breadboards for only £11.19 on Amazon at: **https://amzn.to/3O2L3e8**

Another thing we're going to need are multicore jumper wires. These are typically presented in rainbow-coloured ribbons of various lengths from which we peel off individual wires as required. 4-inch and 8-inch lengths tend to be the most useful, but it doesn't hurt to have a few 12-inch jumpers lying around. These little scamps come in male-male, male-female, and female-female flavors (Fig.7), but all we will need for our experiments are the male-male configuration. You can buy a starter set of 40 wires for £4.49 on Amazon (**https://amzn.to/3O4hnxk**), but this is a case of 'the more the merrier,' so it wouldn't hurt to get more if you can afford to do so.

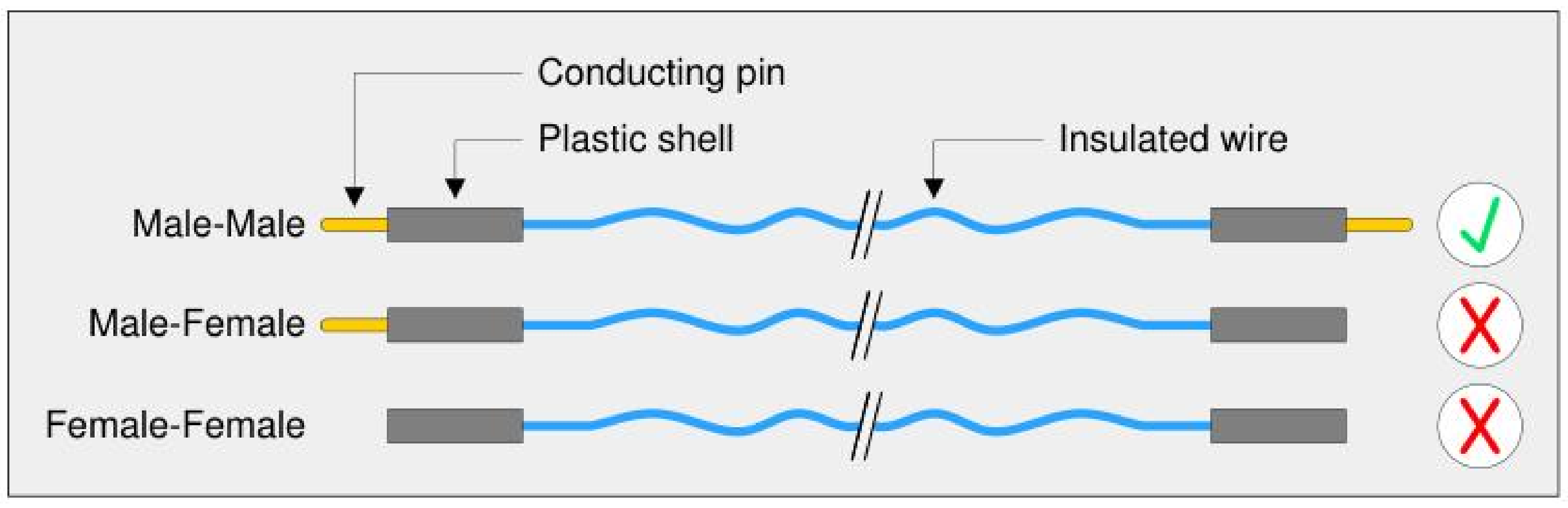


Fig.7. Multicore jumper wires.

Additional bits and pieces

We are going to need a single LED for our first set of breadboard experiments. If you happen to have one laying around, then let's use that. Otherwise, on the basis that LEDs come in handy for so many projects, it really can't hurt to purchase a box of assorted colours. I just found a box of 300 yellow, red, green, blue and white LEDs for only £7.09 on Amazon at: **https://amzn.to/3E7VAQE**

We're also going to need a current-limiting resistor to go with our LED, otherwise it will quickly become an ex-LED. Every LED has two important parameters: its forward-voltage drop (V_F) and its maximum forward current (I_F). Ohm's law states that $V = I \times R$ (with units in ohms, volts and amps, respectively). Since we wish to calculate R in this case, we rearrange things to give $R = V/I$. The way we calculate the value of the current-limiting resistor is to subtract V_F from the supply voltage (which is 5V in our case) and divide the result by I_F.

I just pulled a green LED out of my treasure chest of parts. The data sheet says that this LED's V_F = 3V and its I_F = 20mA (that is, 0.02A), which means that my current-limiting resistor needs to be (5V – 3V) / 0.02A = 100Ω. This value of resistor will have brown-black-brown colour bands.

Resistors are available in a fixed set of values (visit here: **https://bit.ly/3O01LLj** for more details about resistor values and colour bands). If, when you perform your own current-limiting calculation, the result doesn't exactly match one of the available resistor values, use the next higher value, which will result in a slightly lower current (you don't want to use the next lower resistor value because this will result in a current that's higher than the LED's specified maximum).

If I were a betting man, I'd say we will almost certainly be using a bunch of 100Ω and/or 150Ω resistors during the course of our experiments, along with other assorted values. On the basis that, like LEDs, resistors always come in handy, I would suggest purchasing a variety pack, such as the 1,350-piece set I just found for £12.99 on Amazon at: **https://amzn.to/3O4RvBt**

Setting up the breadboard

We can power our breadboard in various ways. For the sake of these discussions, we will power the breadboard from our Arduino (Fig.8). This is the way in which I usually set up the breadboards for all my projects. When I connect the USB cable to the Arduino Uno and the green LED on the breadboard lights up: (a) I know that my power and ground rails are connected and (b) I already have a bright green LED glowing before I start building my main project (a glowing LED always makes me happy).

One of the things I can't stress too strongly is that it's a really, *really* good idea for you to pick a colour scheme for your wiring and then stick to it. For example, I use red wires for power (5V), black wires for ground (0V), and other colours for control and data signals. This may seem like an obvious point, but you'd be amazed how tempting it can be to use whatever wire comes to hand in the heat of the moment. Sticking to a defined scheme makes it easier to understand and debug your circuits should problems arise later.

Does anything you see in Fig.8 cause you to think 'What? Wait! Why did he do that?' If so, it might be a good idea to bounce over to my *Cool Beans* website to peruse and ponder the special breadboard column I wrote just for you – see: **https://bit.ly/3NZ70uF**

Controlling the LED's anode

Suppose we wish to use our Arduino to control the green LED on our breadboard. One way to do this is to leave the LED's cathode connected to 0V (GND) and use one of the Uno's digital I/O pins to drive the LED's anode via its current-limiting resistor (Fig.9a). We are going to use the Arduino's digital I/O pin 6 for this purpose. Why pin 6? There are two reasons: (1) it's not pin 13 (we want to mix things up a bit) and (2) six is my lucky number.

Let's start by repositioning the resistor and adding an orange jumper wire from pin 6 on the Arduino to the breadboard, as illustrated in Fig.9a. Next, we are going to modify the first version of our own *Blink* program which we introduced in Fig.5. Actually, we're going to modify the first tweaked version – the one where we set the On time to 100ms and the Off time to 900ms.

All we really need to do is replace the number 13 with the number 6, but we have to do this three times and I'm feeling lazy. This isn't a huge problem in this case, but it could become so if our program were hundreds or thousands of lines long. One alternative approach is to use a `#define` preprocessor directive, as illustrated in Listing 1 (overleaf).

In this case, we are using the `#define` directive to equate something we are calling `PIN_LED` (the pin driving our LED) with the number 6. Following this definition, every time the preprocessor sees the `PIN_LED` string of characters in the body of the program, it will replace it with the number 6.

Definitions of this type can use both uppercase and lowercase characters (along with numbers and underscore characters). Like many professional programmers, however, I use only uppercase and underscore characters for this sort of constant definition because this makes it obvious to me what they are when I'm reading my code at a later date

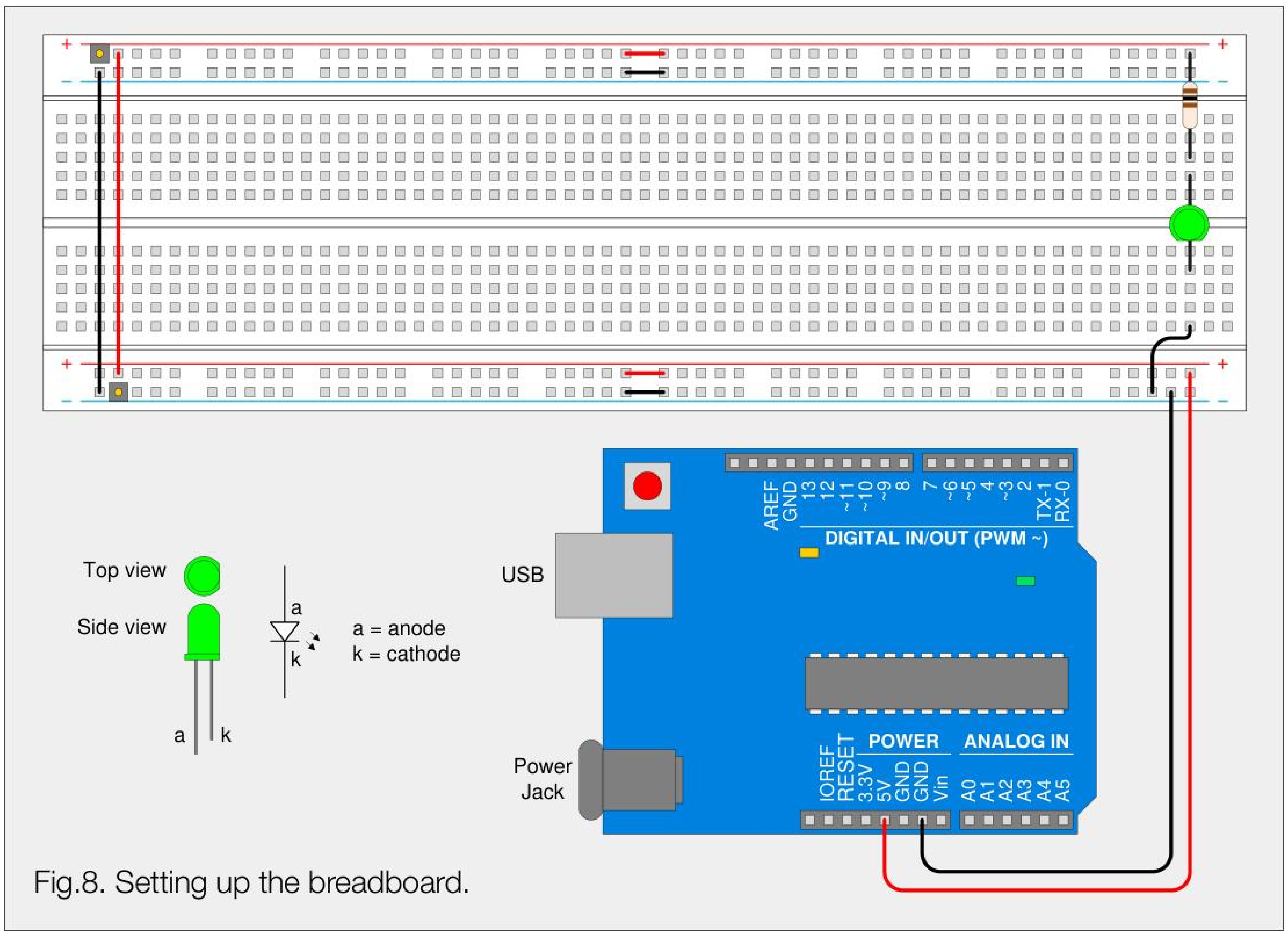
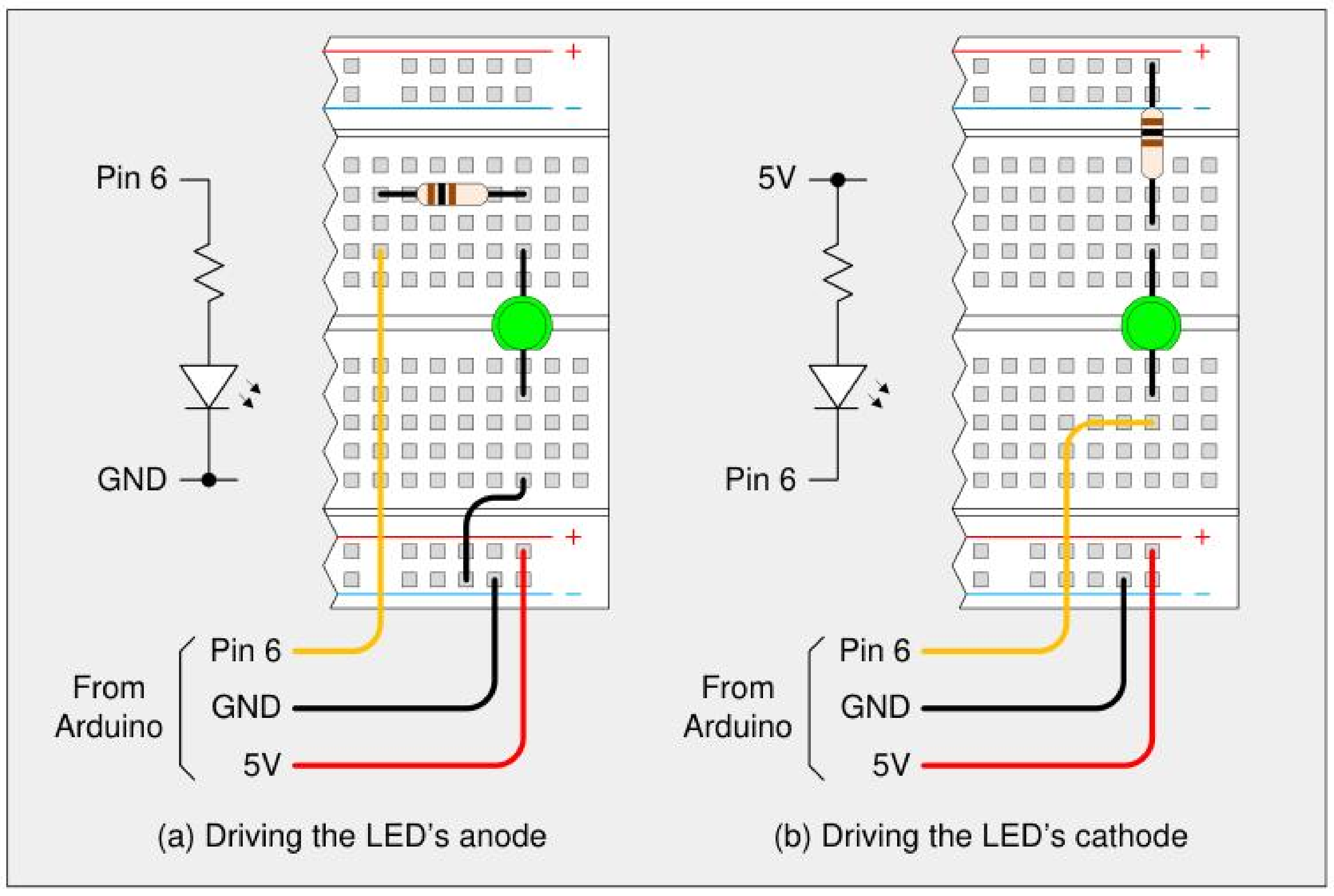


Fig.8. Setting up the breadboard.



(a) Driving the LED's anode

(b) Driving the LED's cathode

Fig.9. Different ways of driving the LED.

(speaking of which, you can see my version of this program in file **CB-Jan23-03.txt**).

Once you've made these changes, click the Verify icon to ensure that all is as it should be, then click the Upload icon to upload this new program into the Arduino. If you've wired everything correctly, the LED on your breadboard should start to display a 1/10th second flash once a second.

Controlling the LED's cathode

An alternative way of controlling the LED is to leave its anode connected to 5V via its current-limiting resistor, and to use one of the Uno's digital I/O pins to drive its cathode. Once again, we will use pin 6 for this purpose. Rewire the breadboard as shown in Fig.9b (remember to remove the black wire connecting the LED's cathode to ground).

Observe that, this time, using our current program, the LED is On for 9/10th of a second and it flashes Off for 1/10th of a second. The reason for this is that when we use our `digitalWrite()` function to output logical values of `LOW` or `HIGH`, these appear on the pin as physical values of 0V and 5V, respectively.

When the Arduino's pin was connected to the LED's anode as discussed above, a `HIGH` (5V) turned the LED On and a `LOW` (0V) turned it Off, all of which tends to be the way in which we think about things. However, now that we've connected the Arduino's pin to the LED's cathode, a `HIGH` (5V) turns the LED Off and a `LOW` (0V) turns it On.

Components

Microcontroller: Arduino Uno R3	**https://amzn.to/3TFkltu**
LEDs (assorted colours)	**https://amzn.to/3E7VAQE**
Resistors (assorted values)	**https://amzn.to/3O4RvBt**
Solderless breadboard	**https://amzn.to/3O2L3e8**
Multicore jumper wires (M2M)	**https://amzn.to/3O4hnxk**

Other recommended stuff

Anti-static mat	**https://amzn.to/3g1YH4A**
Anti-static wrist strap	**https://amzn.to/3WYZ9Bu**
Anti-static grounding plug	**https://amzn.to/3hDIcML**

Assuming we prefer our original short On flashes, one way in which we could address this would be to simply swap the two delay values. Another approach would be to leave the delay values 'as-is,' but to swap the `HIGH` and `LOW` arguments. A better option, however, would be to create two new definitions for `LED_ON` and `LED_OFF` (Listing 2 and file **CB-Jan23-04.txt**).

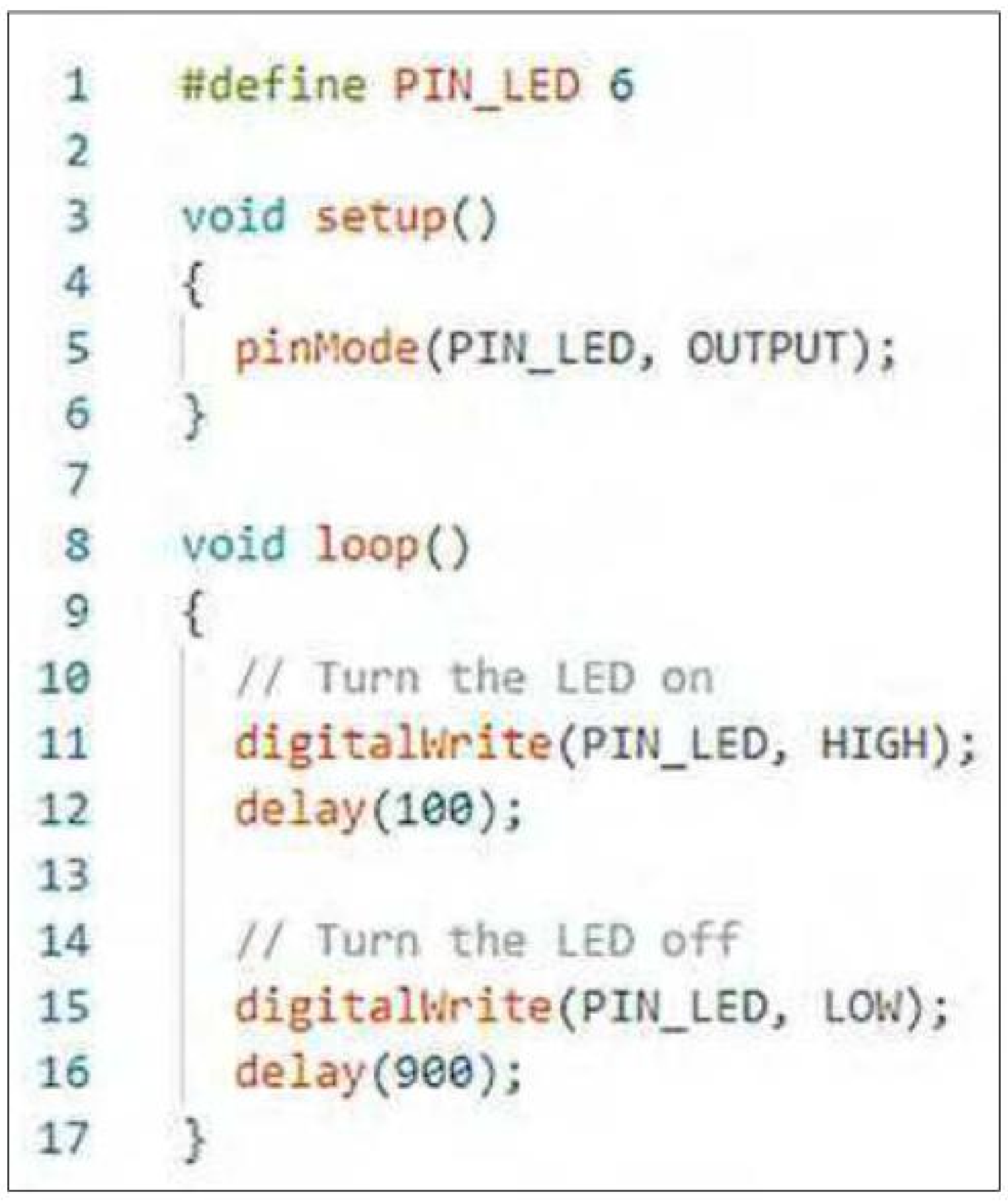
This means that if we wish to return to driving the LED's anode at some time in the future, all we will have to do is swap the `LOW` and `HIGH` assignments associated with our `LED_ON` and `LED_OFF` definitions.

Phew!

'Wanger gadangers,' as one of my old friends used to say, there's a lot to wrap our brains around here. On the one hand, all we've learned thus far is how to use a microcontroller to flash a single LED. On the other hand, WE'VE LEARNED TO FLASH AN LED!!! (Break out the party hats!)

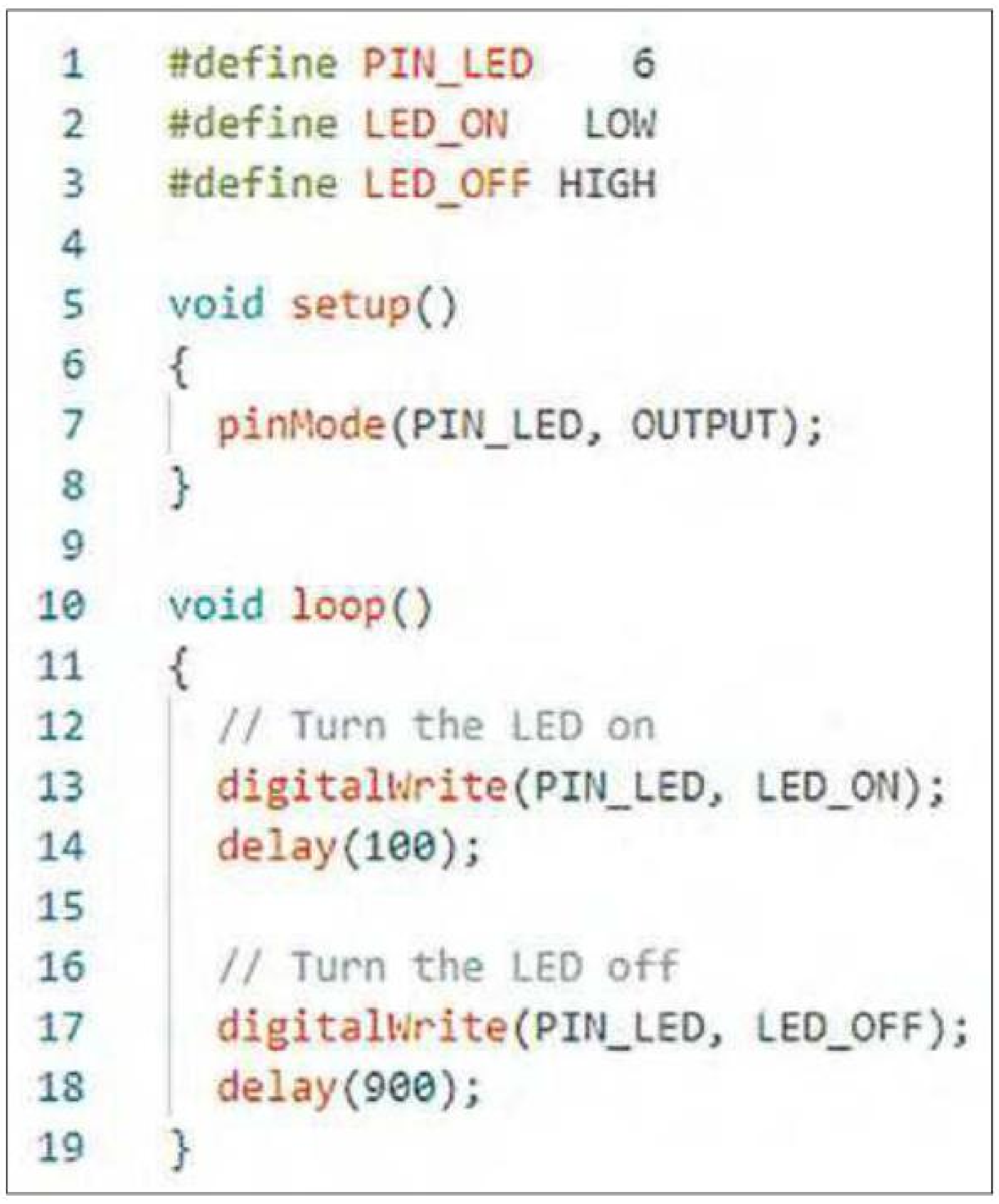
In reality, we've covered a lot of ground and we've set ourselves up for some exciting experiments when next we meet. As a helpful hint, without giving too much away, you may wish to get a head start by ordering one or more common-cathode 1-digit 7-segment displays. I just found a pack of 10 for £7.49 on Amazon at: **https://amzn.to/3Afm8yu**

As always, I welcome your insightful comments, perspicacious questions and sagacious suggestions.



```
#define PIN_LED 6

void setup()
{
  pinMode(PIN_LED, OUTPUT);
}

void loop()
{
  // Turn the LED on
  digitalWrite(PIN_LED, HIGH);
  delay(100);

  // Turn the LED off
  digitalWrite(PIN_LED, LOW);
  delay(900);
}
```

Listing 1. (above) Defining PIN_LED.



```
#define PIN_LED    6
#define LED_ON   LOW
#define LED_OFF HIGH

void setup()
{
  pinMode(PIN_LED, OUTPUT);
}

void loop()
{
  // Turn the LED on
  digitalWrite(PIN_LED, LED_ON);
  delay(100);

  // Turn the LED off
  digitalWrite(PIN_LED, LED_OFF);
  delay(900);
}
```

Listing 2. (right) Defining LED_ON and LED_OFF.

Cool bean Max Maxfield (Hawaiian shirt, on the right) is emperor of all he surveys at **CliveMaxfield.com** – the go-to site for the latest and greatest in technological geekdom.

Comments or questions? Email Max at: **max@CliveMaxfield.com**

Online resources

For the purposes of this series, I'm going to assume that you are already familiar with fundamental concepts like voltage, current and resistance. If not, you might want to start by perusing and pondering a short series of articles I penned on these very topics – see: **https://bit.ly/3EguiJh**

Similarly, I'll assume you are no stranger to solderless breadboards. Having said this, even if you've used these little scamps before, there are some aspects to them that can trap the unwary, so may I suggest you feast your orbs on a column I wrote just for you – see: **https://bit.ly/3NZ70uF**

Last, but not least, you will find a treasure trove of resources at the **Arduino.cc** website, including example programs and reference documentation.

Fluke/Philips PM3092 Oscilloscope
2+2 Channel 200MHz Delay TB,
Autoset etc – £250

STEWART OF READING

17A King Street, Mortimer, near Reading, RG7 3RS
Telephone: **0118 933 1111** Fax: **0118 933 2375**
USED ELECTRONIC TEST EQUIPMENT
Check website **www.stewart-of-reading.co.uk**
(ALL PRICES PLUS CARRIAGE & VAT)
Please check availability before ordering or calling in

HP 54600B Oscilloscope
Analogue/Digital Dual Trace 100MHz
Only £75, with accessories £125

LAMBDA GENESYS	PSU GEN100-15 100V 15A Boxed As New	£400
LAMBDA GENESYS	PSU GEN50-30 50V 30A	£400
IFR 2025	Signal Generator 9kHz – 2.51GHz Opt 04/11	£900
IFR 2948B	Communication Service Monitor Opts 03/25 Avionics	POA
IFR 6843	Microwave Systems Analyser 10MHz – 20GHz	POA
R&S APN62	Syn Function Generator 1Hz – 260kHz	£295
Agilent 8712ET	RF Network Analyser 300kHz – 1300MHz	POA
HP8903A/B	Audio Analyser	£750 – £950
HP8757D	Scaler Network Analyser	POA
HP3325A	Synthesised Function Generator	£195
HP3561A	Dynamic Signal Analyser	£650
HP6032A	PSU 0-60V 0-50A 1000W	£750
HP6622A	PSU 0-20V 4A Twice or 0-50V 2A Twice	£350
HP6624A	PSU 4 Outputs	£400
HP6632B	PSU 0-20V 0-5A	£195
HP6644A	PSU 0-60V 3.5A	£400
HP6654A	PSU 0-60V 0-9A	£500
HP8341A	Synthesised Sweep Generator 10MHz – 20GHz	£2,000
HP83630A	Synthesised Sweeper 10MHz – 26.5 GHz	POA
HP83624A	Synthesised Sweeper 2 – 20GHz	POA
HP8484A	Power Sensor 0.01-18GHz 3nW-10µW	£75
HP8560E	Spectrum Analyser Synthesised 30Hz – 2.9GHz	£1,750
HP8563A	Spectrum Analyser Synthesised 9kHz – 22GHz	£2,250
HP8566B	Spectrum Analsyer 100Hz – 22GHz	£1,200
HP8662A	RF Generator 10kHz – 1280MHz	£750
Marconi 2022E	Synthesised AM/FM Signal Generator 10kHz – 1.01GHz	£325
Marconi 2024	Synthesised Signal Generator 9kHz – 2.4GHz	£800
Marconi 2030	Synthesised Signal Generator 10kHz – 1.35GHz	£750
Marconi 2023A	Signal Generator 9kHz – 1.2GHz	£700

Marconi 2305	Modulation Meter	£250
Marconi 2440	Counter 20GHz	£295
Marconi 2945/A/B	Communications Test Set Various Options	POA
Marconi 2955	Radio Communications Test Set	£595
Marconi 2955A	Radio Communications Test Set	£725
Marconi 2955B	Radio Communications Test Set	£800
Marconi 6200	Microwave Test Set	£1,500
Marconi 6200A	Microwave Test Set 10MHz – 20GHz	£1,950
Marconi 6200B	Microwave Test Set	£2,300
Marconi 6960B	Power Meter with 6910 sensor	£295
Tektronix TDS3052B	Oscilloscope 500MHz 2.5GS/s	£1,250
Tektronix TDS3032	Oscilloscope 300MHz 2.5GS/s	£995
Tektronix TDS3012	Oscilloscope 2 Channel 100MHz 1.25GS/s	£450
Tektronix 2430A	Oscilloscope Dual Trace 150MHz 100MS/s	£350
Tektronix 2465B	Oscilloscope 4 Channel 400MHz	£600
Farnell AP60/50	PSU 0-60V 0-50A 1kW Switch Mode	£300
Farnell XA35/2T	PSU 0-35V 0-2A Twice Digital	£75
Farnell AP100-90	Power Supply 100V 90A	£900
Farnell LF1	Sine/Sq Oscillator 10Hz – 1MHz	£45
Racal 1991	Counter/Timer 160MHz 9 Digit	£150
Racal 2101	Counter 20GHz LED	£295
Racal 9300	True RMS Millivoltmeter 5Hz – 20MHz etc	£45
Racal 9300B	As 9300	£75
Solartron 7150/PLUS	6½ Digit DMM True RMS IEEE	£65/£75
Solatron 1253	Gain Phase Analyser 1mHz – 20kHz	£600
Solartron SI 1255	HF Frequency Response Analyser	POA
Tasakago TM035-2	PSU 0-35V 0-2A 2 Meters	£30
Thurlby PL320QMD	PSU 0-30V 0-2A Twice	£160 – £200
Thurlby TG210	Function Generator 0.002-2MHz TTL etc Kenwood Badged	£65

HP/Agilent HP 34401A Digital
Multimeter 6½ Digit £325 – £375

HP33120A	Function Generator 100 microHz – 15MHz	£350
HP53131A	Universal Counter 3GHz Boxed unused	£600
HP53131A	Universal Counter 225MHz	£350
Audio Precision	SYS2712 Audio Analyser – in original box	POA
Datron 4708	Autocal Multifunction Standard	POA
Druck DPI 515	Pressure Calibrator/Controller	£400
Datron 1081	Autocal Standards Multimeter	POA
ENI 325LA	RF Power Amplifier 250kHz – 150MHz 25W 50dB	POA
Keithley 228	Voltage/Current Source	POA
Time 9818	DC Current & Voltage Calibrator	POA

Marconi 2955B Radio
Communications Test Set – £800

BACK ISSUES

Practical Electronics

BACK ISSUES – ONLY £5.95

We can supply back issues of PE/EPE by post.

We stock magazines back to 2006, except for the following:

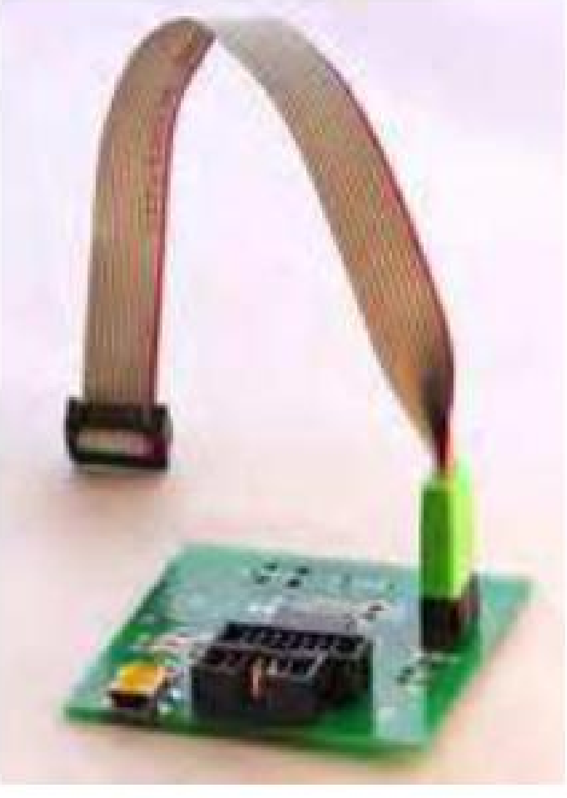
2006 Jan, Feb, Mar, Apr, May, Jul
2007 Jun, Jul, Aug
2008 Aug, Nov, Dec
2009 Jan, Mar, Apr
2010 May, Jun, Jul, Aug, Oct, Nov
2011 Jan
2014 Jan
2018 Jan, Nov, Dec
2019 Jan, Feb, Apr, May, Jun

Issues from Jan 1999 are available on CD-ROM / DVD-ROM

If we do not have a a paper version of a particular issue, then a PDF can be supplied – your email address must be included on your order.

Please make sure all components are still available before commencing any project from a back-dated issue.

Tag-Connect



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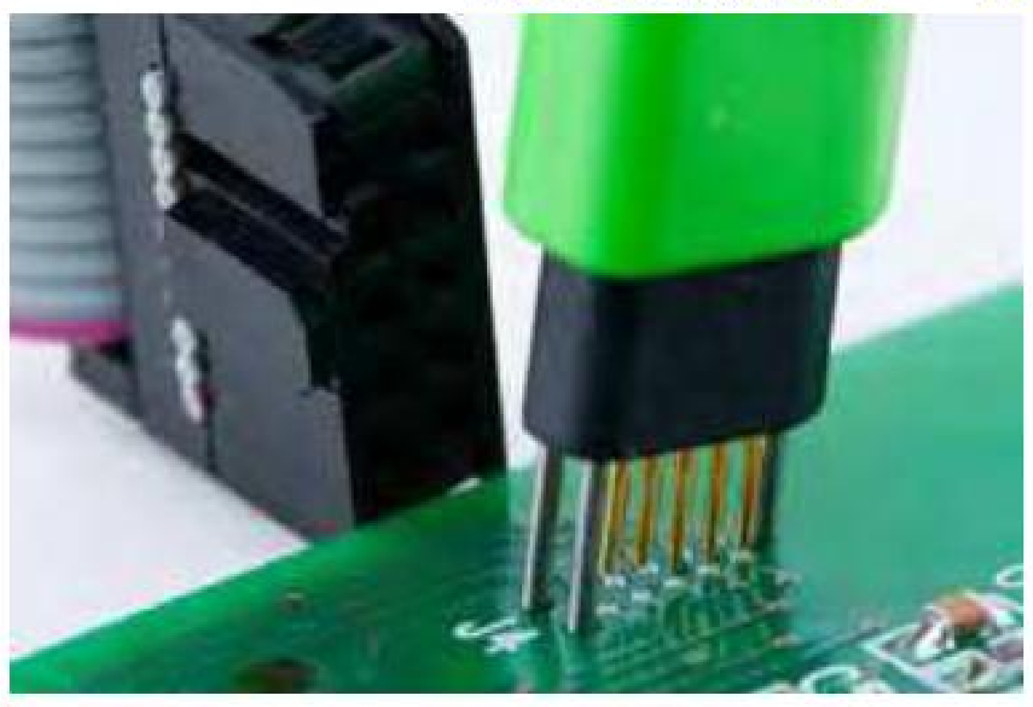

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Classic LED Metronome – 10-LED	23111212	8.95
Multi-Channel Speaker Protector – 6 channel	01101221	9.95
Multi-Channel Speaker Protector – 4 channel	01101222	7.95
Remote Control Range Extender – IR-to-UHF	15109212	5.95
Remote Control Range Extender – UHF-to-IR	15109211	7.95
AO Universal Single Op Amp Board	AO1-JAN23	7.95
DECEMBER 2022		
Hummingbird Amplifier	01111211	9.95
SMD Trainer PCB	29106211	8.95
SMD Trainer PCB + parts	29106211	13.95
NOVEMBER 2022		
USB Cable tester – main PCB	04108211	12.95
USB Cable tester – front panel	04108212	5.95
USB Cable tester – optional panel	SC5970	5.95
Model Railway Carriage Lights – PCB	09109211	6.95
AO transfmr PCB – standard VTX-A range	VTX-101-007	6.95
AO transfmr PCB – dual-outline VTX102-3001/101-3002	VTX-Dual	6.95
OCTOBER 2022		
SMD Test Tweezers – PCB and pair of tweezer arms	04106211-2	11.95
SMD Test Tweezers – programmed PIC12F1572-I/SN	0410621A	7.95
Tele-com	12110211	12.95
SEPTEMBER 2022		
Touchscreen Digital Preamp – main board	01103191	12.95
Touchscreen Digital Preamp – adaptor board pair	01103192	5.95
20A DC Motor Speed Controller	11006211	9.95
AUGUST 2022		
Multi-purpose Battery Manager – I/O Expander module	11104212	5.95
Multi-purpose Battery Manager – Switch Module	11104211	8.95
Simple MIDI Music Keyboard (for 8 switches)	23101213	6.95
Nano Pong	08105212	7.95
JULY 2022		
Silicon Labs AM/FM/SW Radio	CSE210301C	10.95
Level Crossing Controller	09108211	6.95
JUNE 2022		
Full-wave Motor Speed Controller	1010221	8.95
PIC Programming Helper for 8-pin PICs only	24106211	7.95
PIC Programming Helper for 8, 14 or 20-pin PICs	24106212	10.95
Advanced GPS Computer	05102211	9.95
MAY 2022		
Bus board PCB for Analogue Vocoder	AO1-MAY22	10.95
Complete set of 14 PCBs for Analogue Vocoder	AO2-MAY22	97.95
Programmed EEPROM for Digital FX Unit	FX1-MAY22	10.95
Programmed PIC for Digital FX Unit using potentiometer	FX2-MAY22	8.95
APRIL 2022		
64-key MIDI Matrix shield	23101211	8.95
64-key MIDI Matrix switch board	23101212	11.95
High-current Battery Balancer	14102211	10.95
Digital FX Unit – using potentiometer	01102211	9.95
Digital FX Unit – using BCD switch	01102212	9.95
Universal Audio PSU	AO1-APR22	11.95
MARCH 2022		
Mini Isolated Serial Link	24102211	£5.95
Busy Loo Indicator	16112201	£5.95
Analogue Vocoder – Band-pass filter board	AO1-MAR22	9.95
Analogue Vocoder – HP/LP filter board	AO2-MAR22	9.95

PROJECT	CODE	PRICE
FEBRUARY 2022		
Arduino-based Power Supply	18106201	9.95
Battery Monitor Logger	11106201	10.95
Electronic Wind Chimes	23011201	10.95
Analogue Vocoder – Driver Amplifier	AO-FEB22	8.95
JANUARY 2022		
Vintage battery Radio Li-ion Power Supply	11111201	9.95
MiniHeart: A Miniature Heartbeat Simulator	01109201	8.95
DECEMBER 2021		
AM/FM/SW Digital Receiver	CSE200902A	13.95
Balanced Input and Attenuator for USB CODEC	01106202	11.95
NOVEMBER 2021		
Dual Battery Lifesaver	11111202	£6.95
OCTOBER 2021		
Mini Wi-Fi LCD BackPack	24106201	£8.95
SEPTEMBER 2021		
USB SuperCodec PCB	01106201	£14.95
Audio DDS Oscillator PCB	01110201	£5.95
Audio DDS Oscillator rotary encoder	01110201-ENC	6.95
Programming Adaptor Board for Audio DDS Oscillator	01110202	£5.95
High-power Ultrasonic Cleaner main PCB	04105201	£14.95
High-power Ultrasonic Cleaner front-panel PCB	04105202	
Night Keeper Lighthouse PCB	08110201	£5.95
AUGUST 2021		
Ol' Timer PCB	19104201	£11.95
Ol' Timer 8x8 RGB LED module using WS2812B	19104201-88	£8.95
Ol' Timer set of acrylic case pieces and spacer	19104201-ACR	£8.75
Ol' Timer DS3231 RTC IC wide SOIC-16	19104201-RTC	£5.95
Wideband Digital RF Power Meter	04106201	£9.75
Switchmode 78xx regulators ***(PACK of 5!)***	18105201	£7.95
Cool Beans SMAD display	CB-AUG21	£11.95
JULY 2021		
ATtiny816 Breakout / Dev Board with Capacitive Touch	24110181	£9.75
IR Remote Control Assistant (Jaycar version)	15005201	£8.95
IR Remote Control Assistant (Altronics version)	15005202	£8.95
PIC18F Development Board	PNM-JUL21	£12.95
Microphone Preamplifier	AO-JUL21	£11.95
JUNE 2021		
Roadies' Test Signal Generator (surface-mount version)	01005201	£8.95
Roadies' Test Signal Generator (through-hole version)	01005202	£9.95
Touchscreen Wide-range RCL Box (Resistor module)	04104201	£18.95
Touchscreen Wide-range RCL Box (Ind/Cap module)	04104202	
KickStart Part 3 – Gyrator-based Audio Filter	KS3-2021	£7.95
MAY 2021		
7-Band Equaliser (Mono)	01104201	£8.95
7-Band Equaliser (Stereo)	01104202	£10.95
Car Altimeter	05105201	£7.95
APRIL 2021		
Reflow Oven – DSP Active Crossover (CPU)	01106193	£19.95
Reflow Oven – DSP Active Crossover (Front panel)	01106195	
Reflow Oven – DSP Active Crossover (LCD)	01106196	
Frequency Reference Signal Distributor	CSE200103	£8.95

PCBs for most recent *PE*/*EPE* constructional projects are available. From the July 2013 issue onwards, PCBs with eight-digit codes have silk screen overlays and, where applicable, are double-sided, have plated-through holes, and solder mask. They are similar to photos in the project articles. Earlier PCBs are likely to be more basic and may not include silk screen overlay, be single-sided, lack plated-through holes and solder mask.

Always check price and availability in the latest issue or online. A large number of older boards are listed for ordering on our website.

In most cases we do not supply kits or components for our projects. For older projects it is important to check the availability of all components before purchasing PCBs.

Back issues of articles are available – see Back Issues page for details.

Double-sided | plated-through holes | solder mask

PROJECT	CODE	PRICE
MARCH 2021		
Nutube Guitar Effects Pedal	01102201	£12.95
Programmable Thermal Regulator (Peltier Interface)	21109181	£18.95
Programmable Thermal Regulator (Peltier Driver)	21109182	
Tunable HF Preamp	CSE190502	£8.95
FEBRUARY 2021		
4G Remote Monitoring	27111191	£9.95
JANUARY 2021		
Nutube Valve Preamplifier	01112191	£12.95
Arduino DCC Controller	09207181	£10.95
DECEMBER 2020		
Pseudo-Random Sequence Generator	16106191	£7.95
Clever Charger	14107191	£11.95
PE Theremin Amplifier	AO-1220-01	£8.95
NOVEMBER 2020		
LED Christmas Tree (1 off)	16107181-1	£6.95
LED Christmas Tree (4 off)	16107181-2	£14.95
LED Christmas Tree (12 off)	16107181-3	£24.95
LED Christmas Tree (20 off)	16107181-4	£34.95
USB/SPI Interface Board	16107182	£5.95
45V/8A Power Supply PCB *plus* acrylic spacer	18111181	£14.95
45V/8A Power Supply front panel five-way display bezel	18111181-BZ	£3.95
Five-way LCD Panel Meter/Display	18111182	£7.95
OCTOBER 2020		
Digital Audio Millivoltmeter	04108191	£9.95
Precision Signal Amplifier	04107191	£7.95
SEPTEMBER 2020		
PE Theremin PSU	AO-0920-01	£5.95
PE Theremin PSU transformer	AO-0920-02	£7.95
Micromite Explore-28	07108191	£6.95
Ultrabrite LED Driver	16109191	£6.95
AUGUST 2020		
Micromite LCD BackPack V3	07106191	£9.95
Steering Wheel Audio Button to Infrared Adaptor	05105191	£7.95
JULY 2020		
AM/FM/CW Scanning HF/VHF RF Signal Generator	04106191	£13.95
Speech Synthesiser with the Raspberry Pi Zero	01106191	£5.95
PE Mini-organ PCB	AO-0720-01	£14.95
PE Mini-organ selected parts	AO-0720-02	£8.95
High-current Solid-state 12V Battery Isolator – control	05106191	£6.95
High-current Solid-state 12V Battery Isolator FET (2oz)	05106192	£9.95
JUNE 2020		
Arduino breakout board – 3.5-inch LCD Display	24111181	£6.95
Six-input Audio Selector main board	01110191	£10.95
Six-input Audio Selector switch panel board	01110192	
MAY 2020		
Ultra-low-distortion Preamplifier Input Selector	01111112	£11.25
Ultra-low-distortion Preamplifier pushbutton Input Selector	01111113	
Universal Regulator	18103111	£7.95
433MHz Wireless Data Repeater	15004191	£8.50
Bridge-mode Adaptor for Amplifier	01105191	£7.95
iCEstick VGA Terminal	02103191	£5.95
Analogue noise with tilt control	AO-0520-01	£7.95
Audio Spectrum Analyser	PM-0520-01	£8.95

PROJECT	CODE	PRICE
APRIL 2020		
Flip-dot Display black coil board	19111181	£14.95
Flip-dot Display black pixels	19111182	
Flip-dot Display black frame	19111183	
Flip-dot Display green driver board	19111184	
MARCH 2020		
Diode Curve Plotter	04112181	£10.95
Steam Train Whistle / Diesel Horn Sound Generator	09106181	£8.50
Universal Passive Crossover (one off)	UPC0320	£12.50
FEBRUARY 2020		
Motion-Sensing 12V Power Switch	05102191	£5.95
USB Keyboard / Mouse Adaptor	24311181	£8.50
DSP Active Crossover (ADC)	01106191	£29.95
DSP Active Crossover (DAC) ×2	01106192	
DSP Active Crossover (CPU)	01106193	
DSP Active Crossover (Power/routing)	01106194	
DSP Active Crossover (Front panel)	01106195	
DSP Active Crossover (LCD)	01106196	
JANUARY 2020		
Isolated Serial Link	24107181	£8.50

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NOTE: Most boards are in stock and sent within seven days of receipt of order, please allow up to 28 days delivery if we need to restock.

Practical Electronics PCB SERVICE

PROJECT	CODE	PRICE
DECEMBER 2019		
Extremely Sensitive Magnetometer	04101011	£16.75
Four-channel High-current DC Fan and Pump Controller	05108181	£8.75
Useless Box	08111181	£11.50
NOVEMBER 2019		
Tinnitus & Insomnia Killer (Jaycar case – see text)	01110181	£9.95
Tinnitus & Insomnia Killer (Altronics case – see text)	01110182	£9.95
OCTOBER 2019		
Programmable GPS-synced Frequency Reference	04107181	£11.50
Digital Command Control Programmer for Decoders	09107181	£9.95
Opto-isolated Mains Relay (main board)	10107181	£11.50
Opto-isolated Mains Relay (2 × terminal extension board)	10107182	
AUGUST 2019		
Brainwave Monitor	25108181	£12.90
Super Digital Sound Effects Module	01107181	£6.95
Watchdog Alarm	03107181	£8.00
PE Theremin (three boards: pitch, volume, VCA)	PETX0819	£19.50
PE Theremin component pack (see p.56, August 2019)	PETY0819	£15.00
JULY 2019		
Full-wave 10A Universal Motor Speed Controller	10102181	£12.90
Recurring Event Reminder	19107181	£8.00
Temperature Switch Mk2	05105181	£10.45
JUNE 2019		
Arduino-based LC Meter	04106181	£8.00
USB Flexitimer	19106181	£10.45
MAY 2019		
2× 12V Battery Balancer	14106181	£5.95
Deluxe Frequency Switch	05104181	£10.45
USB Port Protector	07105181	£5.95
APRIL 2019		
Heater Controller	10104181	£14.00
MARCH 2019		
10-LED Bargraph Main Board	04101181	£11.25
+Processing Board	04101182	£8.60
FEBRUARY 2019		
1.5kW Induction Motor Speed Controller	10105122	£24.95
NOVEMBER 2018		
Super-7 AM Radio Receiver	06111171	£15.95
OCTOBER 2018		
6GHz+ Touchscreen Frequency Counter	04110171	£12.95
Two 230VAC MainsTimers	10108161 10108162	£11.95
SEPTEMBER 2018		
3-Way Active Crossover	01108171	£17.95
Ultra-low-voltage Mini LED Flasher	16110161	£5.95
AUGUST 2018		
Universal Temperature Alarm	03105161	£7.95
Power Supply For Battery-Operated Valve Radios	18108171 18108172 18108173 18108174	£24.95
JULY 2018		
Touchscreen Appliance Energy Meter – Part 1	04116061	£14.95
Automotive Sensor Modifier	05111161	£12.95
JUNE 2018		
High Performance 10-Octave Stereo Graphic Equaliser	01105171	£14.95
MAY 2018		
High Performance RF Prescaler	04112162	£10.45
Micromite BackPack V2	07104171	£8.45
Microbridge	24104171	£5.95
APRIL 2018		
Spring Reverberation Unit	01104171	£13.95
DDS Sig Gen Lid	Black	£5.95
DDS Sig Gen Lid	Blue	£5.95
DDS Sig Gen Lid	Clear	£5.95
MARCH 2018		
Stationmaster Main Board	09103171	£17.75
+ Controller Board	09103172	
SC200 Amplifier Module – Power Supply	01109111	£16.45
FEBRUARY 2018		
GPS-Synchronised Analogue Clock Driver	04202171	£11.95
High-Power DC Motor Speed Controller – Part 2		
+ Control Board	11112161	£11.95
+ Power Board	11112162	£15.30
JANUARY 2018		
High-Power DC Motor Speed Controller – Part 1	11112161	£15.30
Build the SC200 Amplifier Module	01108161	£13.95
DECEMBER 2017		
Precision Voltage and Current Reference – Part 2	04110161	£14.95
NOVEMBER 2017		
50A Battery Charger Controller	11111161	£12.95
Micropower LED Flasher (45 × 47mm)	16109161	£7.95
(36 × 13mm)	16109162	£5.95
Phono Input Converter	01111161	£7.9
SEPTEMBER 2017		
Compact 8-Digit Frequency Meter	04105161	£12.95
AUGUST 2017		
Micromite-Based Touch-screen Boat Computer GPS	07102122	£10.45
Fridge/Freezer Alarm	03104161	£7.95
JULY 2017		
Micromite-Based Super Clock	07102122	£10.45
Brownout Protector for Induction Motors	10107161	£12.90
JUNE 2017		
Ultrasonic Garage Parking Assistant	07102122	£10.45
Hotel Safe Alarm	03106161	£7.95
100dB Stereo LED Audio Level/VU Meter	01104161	£17.75
MAY 2017		
The Micromite LCD BackPack	07102122	£7.95
Precision 230V/115V 50/60Hz Turntable Driver	04104161	£13.95
APRIL 2017		
Microwave Leakage Detector	04103161	£7.95

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Next Month – in the February issue

Driveway Gate Remote Control

Sliding/swinging gate controllers inevitably fail after some years of service. The solution is to replace the controller with this much more robust design, and since you've built it yourself, it's easy to fix if it does go wrong.

Cooling Fan Controller & Loudspeaker Protector

This board controls up to three cooling fans, switching them on at a preset temperature and ramping their speed up as it increases, preventing overheating while minimising noise. It can also protect loudspeakers from damage while also preventing power switch-on and switch-off thumps.

L.G.
T.G.
RF_IN
RF_OUT
LTDZ

Geekcreit's LTDZ V5.0 Spectrum Analyser

This compact unit can perform spectral analysis from 35MHz to 4.4GHz. It includes a tracking generator for frequency-domain analysis of filters, RF amplifiers and similar items. It needs to be controlled from a PC via a USB cable (which also provides its 5V DC power supply), using a very impressive free application.

Solid-State Flame Discharge Tesla Coil

This relatively small and simple device generates extremely high voltages, enough to form a 'flame discharge' resembling a candle flame. It can also demonstrate wireless power transmission by lighting up neon globes and fluorescent lamps at some distance.

PLUS!

All your favourite regular columns from *Audio Out*, *Cool Beans and Circuit Surgery*, to *Make it with Micromite*, *Techno Talk* and *Net Work*.

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Content may be subject to change

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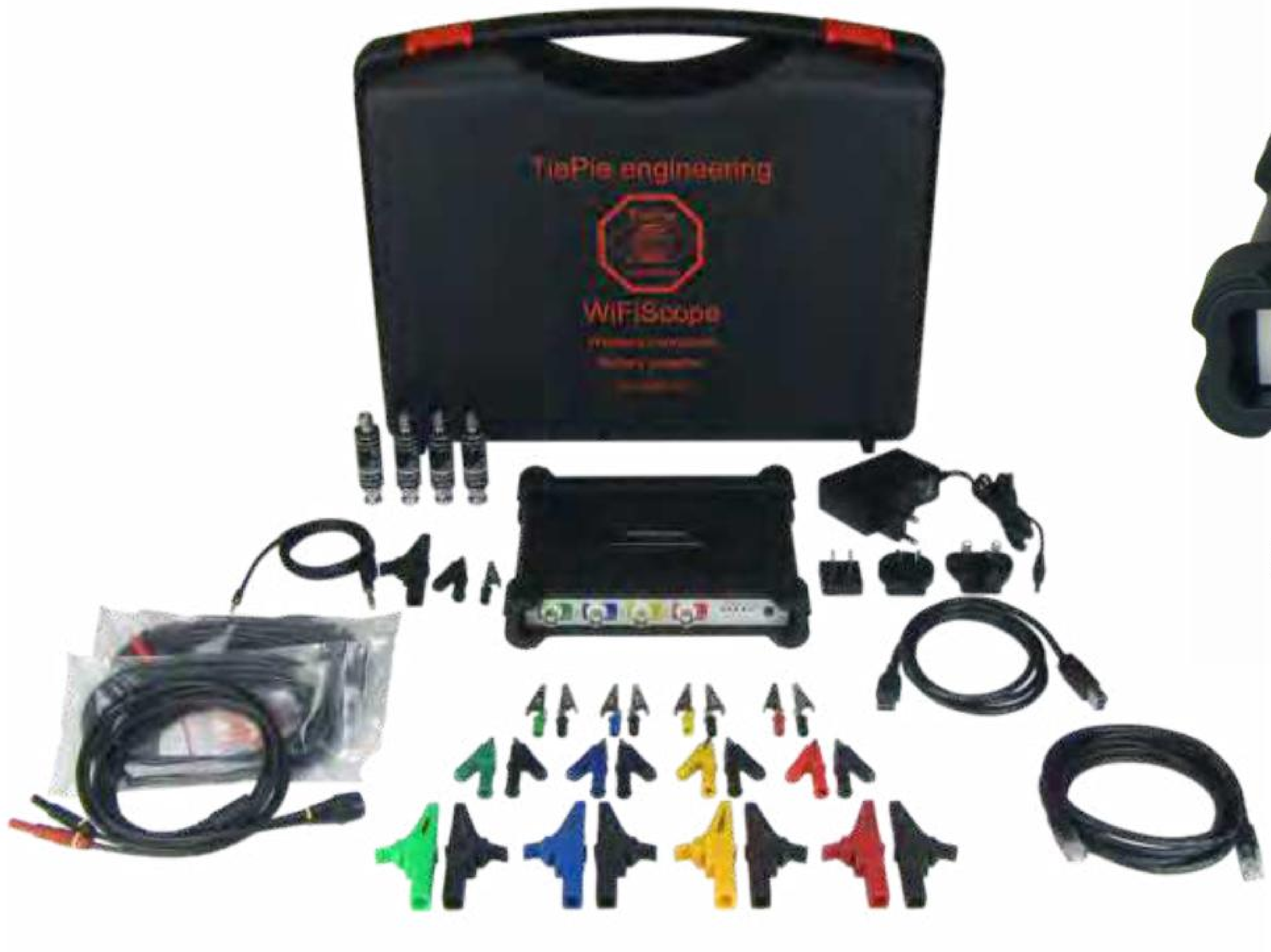

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